TECHNICAL REPORT
72-3-CE

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FOAM FLOTATION SYSTEMS FOR PERSONNEL WEARING BODY ARMOR

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Monsanto Research Corporation
Dayton, Ohio

Contract No. DAAG17-69-C-0017

July 1971

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

U.S. ARMY MATERIEL COMMAND

Clothing & Personal Life Support Equipment
Laboratory
C&PSEL-88

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Clothing and Personal Life Support Equipment Laboratory
U. S. ARMY NATICK LABORATORIES
Natick, Massachusetts

FOREWORD

An investigation was conducted to determine the feasibility of using various flotation systems as an integral part of the aircrew armor system, with three approaches presented and discussed.

The study was conducted by the Monsanto Chemical Corporation, Dayton, Ohio, under Contract No. DAAG17-69-C-0017, for Project Reference 1F164207DC52, of the U. S. Army Natick Laboratories. Mr. Thomas Judge served as the Project Officer for the program.

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ABSTRACT

A feasibility study was conducted on approaches to using foams in flotation systems for personnel wearing body armor.

Flotation systems should be rapidly deployable (10 seconds) and provide flotation for at least six hours, even if damaged. These systems should not interfere with the wearer as he performs his duties.

Three approaches were investigated: (1) the use of preformed flexible foam; (2) instantly generated polystyrene foam; and (3) fast reacting two-component urethane foams.

Only the preformed flexible foam performed well when fabricated into a jacket and tested on a man.

1. INTRODUCTION

The use of body armor for aircrewmen in aircraft operating at low altitudes has become standard practice. This armor furnishes personal protection against small arms fire and fragments from bursting antiaircraft shells. However, its use has increased the problems of personnel evacuating a damaged aircraft in deep water. The previous life saving equipment (armor) then becomes a problem and dangerous to the wearer. It is possible for a strong swimmer, wearing swimming trunks plus armor (front and back plate), to swim for limited times. However, he must swim continuously with a considerable expenditure of effort. If he relaxes or rests from swimming, he sinks immediately. This problem would become more severe if the man were wearing a flight uniform, helmet, boots and other auxiliary equipment. A weak or non-swimmer would find himself in immediate difficulties if he were forced to go into the water wearing armor.

Because of these considerations, it is very desirable to provide some means of providing flotation for a man wearing armor. This flotation should be sufficient to keep a man floating with his head above water. He should also float in such a position that his face is kept out of the water so that he will not drown even though unconscious. In addition, the flotation system should be of such size and positioning that a man wearing it cannot turn over to float face down.

Presently existing flotation systems are not completely suitable in these respects. They are made to be worn close to the body. They cannot be worn over the armor and if worn under the armor, they do not function properly. Even more serious, present equipment is air-inflatable. As such, although it gives excellent flotation properties, the slightest damage to the air-inflated envelope results in these devices becoming completely ineffective.

Because of these reasons there is a need to develop flotation equipment that is compatible with body armor systems currently in use or contemplated, that function quickly and dependably, and provide flotation that is not subject to becoming ineffective when damaged to a reasonable extent.

A program was initiated by the U. S. Army, Natick Laboratories with Monsanto Research Corporation to show the feasibility of using plastic foams to provide flotation. The work was done in three phases, namely:

- Concept development,

- Preliminary design of selected concepts, and

- Building of prototype models to demonstrate the possible utility of the several designs.

2. TECHNICAL DISCUSSION

In this section a number of general considerations are discussed, and each of the flotation concepts that were carried through the program along with concepts and approaches that were not actively pursued are described.

A. Basic Requirements of Flotation Systems

The system to be developed to provide flotation for an aircrewman wearing armor has a number of basic requirements. The system must be incorporated with or be compatible with the body armor now in use. It should not be unduly cumbersome and should not interfere with the function of the armor nor with the aircrewman performing his assigned task. Ideally, the prospective flotation system will be mounted on the armor system and its carrier. As an alternative, if the direct mounting is not feasible, the flotation system could be part of the vest or jacket that is worn over the armor and its carrier. Such a jacket must be made so that it can be securely fastened to the armor and its carrier.

Any proposed system of flotation must be of sufficient volume and of low enough density to float a man wearing customary clothing, equipment, and armor, in either fresh or salt water. The anticipated maximum weight of such an aircrewman plus equipment would be 250 lb. The amount of buoyancy provided should be sufficient to float the wearer with head, neck, and upper shoulders out of the water. The foam should be positioned so that even an unconscious man will float face upward. The flotation system should have sufficient permanence to keep a man afloat for at least six hours.

The flotation system should not weigh more than 4 lb and in the undeployed condition should have a volume of 48 cu in. or less. To ensure adequate flotation the deployed volume should be at least 1300 cu in. This necessitates an approximate 30 fold volume increase between the undeployed and deployed flotation system.

Any system developed under the program should be consistent with normal safety requirements and acceptable to the potential user. This acceptability should be based on safety, ease of operation, compatibility with normal mode of working, and comfort to the user.

The projected systems should be storable for at least one year at +125°F to -20°F, without either physical or mechanical deterioration.

The candidate systems should be activated simply and provide full flotation within 10 seconds at 40°F. Activation of the flotation system should not occur by accident (such as environmental changes, shock, dropping, or vibration). Fail-safe characteristics should be designed into the system and it should be reasonably resistant to damage caused by projectiles.

B. Flotation of a Man in Armor

(1) Theoretical Considerations

The positive buoyancy forces necessary to support in fresh water a fully clothed, large-size individual (216 lb, 98 percentile man) wearing a protective armor were theoretically determined and experimentally verified. Sufficient buoyancy was provided to float a man with his head and portion of the neck above the water level. The individuals were clothed in standard aircrew uniform, crash helmet, and small arms protective armor, and carried other miscellaneous equipment.

The theoretical calculations were based on the available anthropomorphic data* for the average individual as well as weight and specific gravity values for the clothing and the various items of protective equipment as indicated in Table 1. The buoyancy characteristics of some experimental equipment were also considered.

The head of the normal individual is approximately 6.9% of the total mass of the body. Since it must be kept above water, it does not contribute to the positive buoyancy. The same applies to the crash helmet, which is also maintained above the water level. Results of the theoretical calculations based on the above considerations are given in Table 2.

*Bioastronautics Data Book, Paul Webb, MD, editor. NASA-SP-3006, Washington, D. C., 1964

Table 1

WEIGHT AND SPECIFIC GRAVITY DATA FOR THE FLOTATION ARMOR DESIGN

Item	Weight (lb)	Specific Gravity
98 percentile man, endomorphy index 1.06	216.0	1.06
Crash helmet	4.0	above water
Front armor plate assembly	13.0	∿2.6
Back armor plate assembly	9.0	∿1.8
Combat boots, socks, underwear, flight suit, gloves, and misc. equipment	8.0	1.3
5.5 square feet of 0.5 in. thick vinyl en-closed nylon flak vest	1.4	0.1

Table 2

BUOYANCY REQUIREMENTS FOR AIRCREWMAN IN FRESH WATER

Description of Item	Naked Man With Head Above Water	Aircrewman With Aluminum Oxide Armor Front and Back Plate	Aircrewman With Aluminum Oxide Front Plate Assembly Only	Aircrewman With Boron Carbide Armor Front Plate Assembly	Aircrewman With Boron Carbide Front Armor Plate and Nylon Vest
Head of 216 lb man	-14.0	-14.0	-14.0	-14.0	-14.0
Torso of man (202 lb)	-12.0	-12.0	-12.0	-12.0	-12.0
Helmet	--	- 4.0	- 4.0	- 4.0	- 4.0
Front armor plate assembly	--	- 8.0	- 8.0	- 6.0	- 6.0
Back armor plate assembly	--	- 4.0	--	--	--
Clothing, Miscellaneous	--	- 2.0	- 2.0	- 2.0	- 2.0
5.5 sq ft of 0.5 in. thick nylon vest intact	--	--	--	--	+13.0
Total negative buoyancy	-26.0	-44.0	-40.0	-38.0	-25.0

It is evident that approximately 26.0 lb of positive buoyancy or 0.42 cu ft of low density flotation material is required to support a 98 percentile naked man with his head out of the fresh water. The buoyancy force requirement increases to 44.0 lb or approximately 0.70 cu ft of flotation material for aircrewmen wearing the standard uniform and the presently utilized aluminum oxide front armor plate and back armor assembly.

The design of the proposed flotation system is based on the above requirement for the buoyancy force. By elimination of the back plate armor assembly the required buoyancy force can be reduced to 40.0 lb. Further reduction for the flotation can be obtained by substitution of a boron carbide front plate armor assembly for the presently utilized aluminum oxide unit. A positive buoyancy force of 38.0 lb is required in this case.

Utilization of a nylon flak vest is being contemplated at the present time. This vest consists of 5.5 sq ft of 0.5 in. thick nylon felt material enclosed in an airtight vinyl bag. As such this unit would provide an excellent auxiliary flotation device. It is estimated that this unit would reduce the required buoyancy force for a large man to 25.0 lb. Thus, with the nylon flak vest the buoyancy force required to support a fully equipped man with armor would be provided by an additional amount of low density buoyant foam of approximately 0.40 cu ft. This, of course, would considerably reduce the size and weight of the flotation system.

(2) Human Factor Considerations

A number of design and operational advantages and disadvantages have been described for several proposed flotation systems. Each system, despite its innate characteristics, must satisfy certain basic human factor criteria. In addition to the obvious safety, acceptability, and reliability features, some of the more outstanding aspects that are being given consideration for the inactivated and activated device are discussed in the following paragraphs.

(a) Inactivated State

The flotation device must not be significantly additive to the burden imposed on the wearer by the armor alone. It should not impede the ability of a man to perform effectively

his assigned task. The shoulder and auxillary area should be avoided as a place to locate flotation components. Particularly arm-shoulder adduction and arm rotational movements should not be limited. Component positioning should not lead to potential occlusion of circulation or made respiration more difficult. Such might be the case if components were stored under the armor. Protruding components predisposing accidental activation, system rupture, or wearer injury are to be avoided. The system should not be rendered inoperable or ineffective by minimal damage.

(b) Activated State

The position of the buoyant material must be such that the stable position of the man in the water is: face up, head and shoulders out; and body oriented at approximately 45° to the water surface. The flotation should force the man to assume this position regardless of orientation at the time of entry into the water. Not more than a few seconds should be required after the initial water contact is made before full flotation capability is realized. Activation should be a simple one-step procedure, or automatic. Head position should be maintained--face forward with the chin up--by a flotation collar around the neck. The temptation to stow components or fill with flotation material a space between the armor and the man must be avoided or approached with caution. Over-filling would result in making respiration difficult or impossible. Potentially toxic operational materials or by-products should be used only after ruling out the availability of alternative materials. The flotation material should retain its buoyancy well even when directly exposed to water. The flotation material positioning, while performing body orientational function, may also protect the wearer from armor induced injury, i.e. a pad across the top of the breastplate to reduce head injury upon impact.

Perhaps the most difficult requirement is the necessity of the flotation to always orient the wearer properly regardless of body size, physical state (injured or unconscious), or entry orientation. Original estimates had indicated and empirical evidence from pool tests has supported the conclusion that the approximate proportioning of buoyant material should be: 65% upper chest area and 35% around the neck and shoulders. The total amount or volume of material needed to float the 250-lb equipped man is essentially directly calculable if the densities of all of the materials are known.

Whether the above positioning and proportioning will always work despite size variations, movements of limbs, and other considerations must be examined. Attempting to calculate all of the variations of combinations and relate these to their effect on body position in the water is an impossible task; however, some of the human features relative to this problem that can be considered in the selection of the type of buoyant material and its placement on the body are the following:

- A difference in weight of approximately 75 lb exists between the 5th and the 95th percentile. A single flotation capable of floating the 95th percentile man (250 lb including equipment) could increase the roll tendency in the lighter individuals.

- While the total height variation from the 5th to the 95th percentile is about 9 inches, the head and neck segment (to be buoyed up) differs by only 2 inches at the extremes. Moment arms around the center of gravity will vary, altering the angle of flotation for different persons wearing the same flotation.

- The specific gravity for humans can range from 1.02 to 1.10, depending on body fat content. The less dense fat person will float with relatively more volume projecting from the water. This factor may result in orientational problems for a fixed flotation.

- The center of gravity for 90% of the adult male population can be located within an area of the body encompassed by a 2 inch diameter sphere.* A single size and fixed proportion flotation arrangement probably would not be overpowered by this range of variation; however, with movement the center in a given individual can be shifted as much as ±10 inches on the Z axis, 8 inches on the +X and 4.5 inches on the -X axis, and ±4.5 inches on the Y axis. The shifts can conceivably occur without concomitant proportional shifts in the center of displacement resulting in unstable flotation.

*Determination of Centers of Gravity of Man, J. J. Swearingen. FAA Report 62-14, 1962.

- The armor will tend to shift the center of gravity toward the head (+Z) without appreciably altering the center of buoyancy. This creates an unstable condition tending to rotate the man to a head down--feet up position.

- In fresh water the water line of the floating man should probably not be located farther caudally than the level of the vertebra prominens in the rear and the sternal notch in the front.

- The various densities of the man and equipment and their influence on the buoyancy are discussed elsewhere in the report. The trapping of water in a helmet and the effect of waterlogged clothing on the orienting ability of the flotation must be studied.

C. Preformed Flexible Foam as a Flotation Material

The concept of using preformed flexible foam as a flotation material was an outgrowth of previous work done in developing an unsinkable life raft. The use of preformed flexible foam was investigated with encouraging results as one of the approaches to producing such a raft.

(1) General Concept of Using Preformed Foam

If a block of flexible foam is packaged in an airtight envelope of flexible plastic film, and the air is evaculated from the envelope, the foam collapses. Collapse is due to the pressure differential between the outside of the envelope (atmospheric) and the inside of the envelope (0.1 atmosphere or less). Most flexible foams have very low compressive strength, and the pressure differential of $\geq$13.5 psi is more than ample to collapse the foam to only 10% or less of its original volume. This greatly reduces the bulk of the foam for as long as the vacuum is maintained inside the envelope. Upon release of the vacuum the foam expands once more due to its natural resilience. In this expanded condition it once more becomes a buoyant material.

(2) Design of Flotation Gear Using Preformed Foam

The equipment and components necessary to adapt preformed flexible foam to use in an armor flotation system is relatively simple. It consists of the following:

- A fabric envelope to enclose the foam package. This envelope protects the foam package from damage such as snags and tears.

- The foam package, which consists of an outer gas-tight plastic covering for the foam, and the flexible foam itself.

- A gas supply system, which consists of the necessary tubing and manifolds to distribute the inflating gas to the foam-filled flotation ring or jacket, a manual or automatic valve to release the gas, and gas (carbon dioxide) cylinders.

These are the basic components of a flotation system using flexible foam. They furnished the basis for all design considerations on the use of preformed flexible foam to provide buoyance to a man wearing aircrew armor.

(a) Conceptual Development (Phase 1)

No design work was authorized during Phase 1 of the program. However, the details of how a preformed foam might be used as a flotation material were considered.

Swimming pool tests had shown that the bulk of the foam ($\sim$0.5 cu ft) is needed in the chest area. The remainder of the foam ($\sim$0.25 cu ft) should be placed over each shoulder and around the back of the neck.

Design considerations during this phase were influenced by a British life jacket (manufactured by the Frankenstein Group, Ltd., Newton Heath, Manchester) with a flotation collar that encircled the wearers neck and places the bulk of the flotation on the upper chest area. Figure 1 shows a man wearing this jacket over armor.

A simplified sketch of a foam-filled vest is shown in Figure 2. It contains all the essential components to make a flotation system using preformed-flexible foam.

The steps considered in fabricating a flotation jacket from preformed flexible foam were as follows:

Figure 1. Man Wearing British Life Jacket

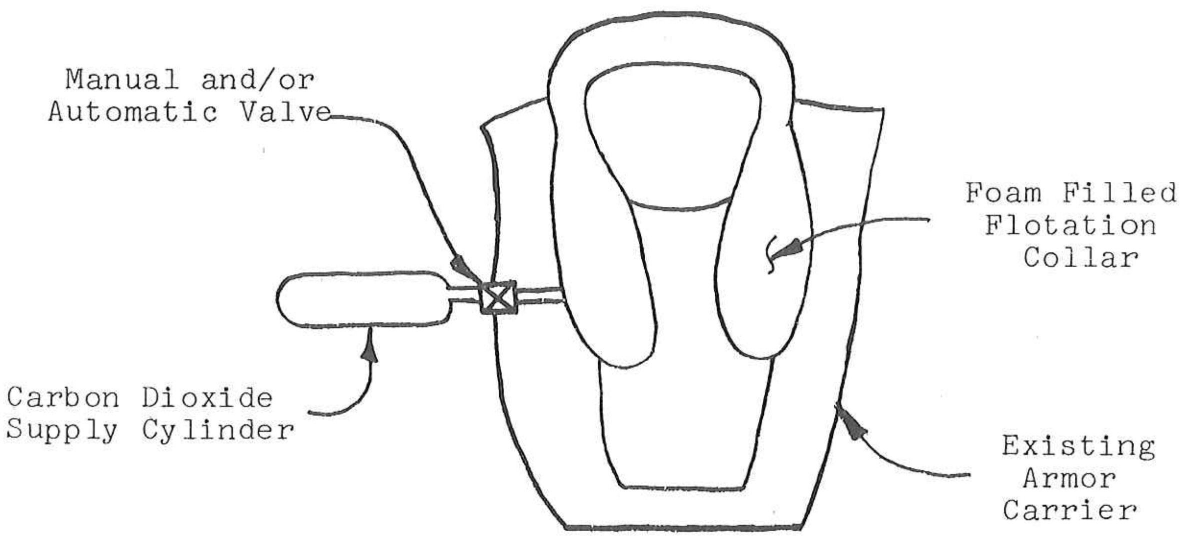


Figure 2. Schematic of Foam Filled Vest

- Cutting of foam to the right size and contour. If a large number of items were to be made it would be better to fabricate molds and cast the foam. For a small number of items and limited budget, cutting was considered better.

- Coating of foam with a water repellant.

- Packaging the treated foam in an airtight, flexible vinyl envelope, and providing means for attaching gas inflation tubes and/or vacuum lines to the envelope. It was considered that it might be well to continue the gas distribution tube into the center of the foam, so that the gas could help to expand the foam if permanent compression set became a problem. Also, consideration was given to adhering the vinyl envelope to the foam surface as an aid to opening the foam. Subsequent compression set data showed that these steps were not necessary.

- Evacuation of foam envelope causing foam to collapse to approximately 10% of its original volume. Tests on pieces of foam showed that this did happen.

- The subdivision of the foam into a number of separately packaged blocks was considered. The packaging of the foam into at least three and possibly five pieces appeared to be desirable. It would provide a number of separate compartments that would help to minimize loss of flotation in case of damage.

- The evacuated foam packages would be assembled into a cloth foam carrier which was visualized at this stage as being a foam collar extending down into the chest area. This would be worn over and attached to the present armor carrier.

- Attachment to the foam collar of a carbon dioxide supply cylinder. Because of requirements for providing flotation to injured and unconscious personnel, a water-actuated automatic inflation system was deemed essential. The carbon dioxide would inflate the foam envelope, destroying the pressure differential between the inside and outside of the foam envelope and thus permit the foam to open.

- Pyrotechnic generation of gas to inflate the foam was considered and tested. Holex Corp #5227 experimental pyrotechnic cartridges were tested. This work was not successful because the cartridges did not function well in the evacuated foam package.

After considering the various aspects of the use of preformed foam, it was considered to be one of the most promising approaches to providing flotation for personnel wearing armor. This was based on the following considerations:

- Light weight
- Compact
- Potentially compatible with existing armor and carrier
- Least interference with aircrewman
- Good flotation properties. Even after puncture, flotation is lost very slowly if at all
- Automatic operation of gas-inflating system appeared to be entirely feasible.

At the end of Phase 1 it was recommended that the preformed flexible foam system be continued into the next phase of the program.

(b) <u>Design of System (Phase 2)</u>

The second phase was devoted to designing a flotation system using precompressed flexible foam.

This design was based on the use of a foam collar that could be fastened securely to the present armor carrier by the use of straps. When not needed, the foam collar could be removed from the carrier.

During this phase the flotation equipment to utilize preformed foam was fully designed and detail drawings were prepared of each part.

The individual components are described in the following sections.

Foam Component

To provide the necessary buoyancy to float a 98 percentile man wearing protective armor, it was proposed to utilize approximately 1300 cu in. (open volume) of either General Tire and Rubber Company P-137 urethane foam or International Company #1553 foam. The foam is enclosed in a vinyl container. The vinyl container in turn is contained in the carrier assembly to be worn over the protective armor. Figures 3 and 4 show assembly views of the system.

The foam is divided into at least three separate sections. Two identical sections having a total volume of approximately 950 cu in. are located in the front chest area of a man. The third section with a volume of approximately 350 cu in. is placed in the upper back area of a man. All three foam sections are placed in a 0.008 in. gage thickness vinyl bag.

Vinyl Envelope

The vinyl bag is either heat sealed and/or sealed with Thixon XAS 138 contact adhesive, manufactured by the Dayton Chemical Products Laboratory, to provide an individual-sealed compartment for each of the three foam sections. The vinyl bag assembly is made to fit over the head and shoulder of the man with the immediate area over the shoulders free from foam. This was done in order not to impair freedom of movement of a man and eliminate bending of evacuated foam around the shoulders. The unevacuated vinyl bag containing foam would be approximately 5 inches thick. Upon evacuation, it was expected that the bag thickness would be reduced to approximately 0.5 inches.

The modified valve assembly is attached to one of the front vinyl foam compartments with Thixon XAS 138 adhesive to provide a vacuum-tight seal. It was expected that several layers of vinyl will be utilized in the immediate area of the valve to provide a strong, snag-free base for the inflation valve assembly. The inflation valve assembly would be modified by inclusion of a CO_2 distribution manifold. Three, 1/8-inch outside diameter Tygon distribution tubes will be required to carry the CO_2 gas to each of the foam compartments. The tubes are inserted into the foam and sealed to the vinyl skin of the compartment with Thixon XAS 138 contact adhesive which has been tested for this use and found to make strong vacuum-tight seals.

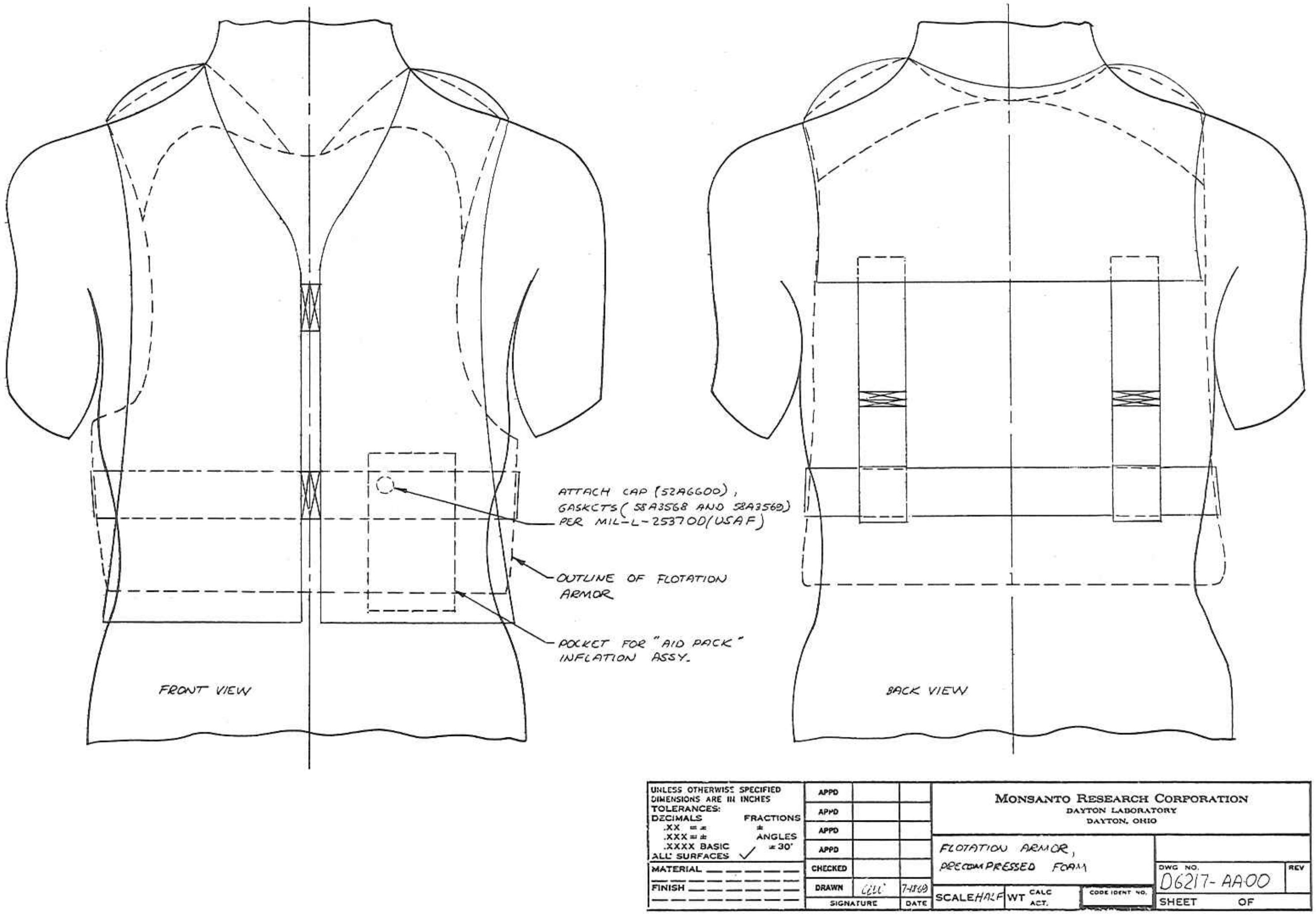


Figure 3. Position of Flotation System on Man

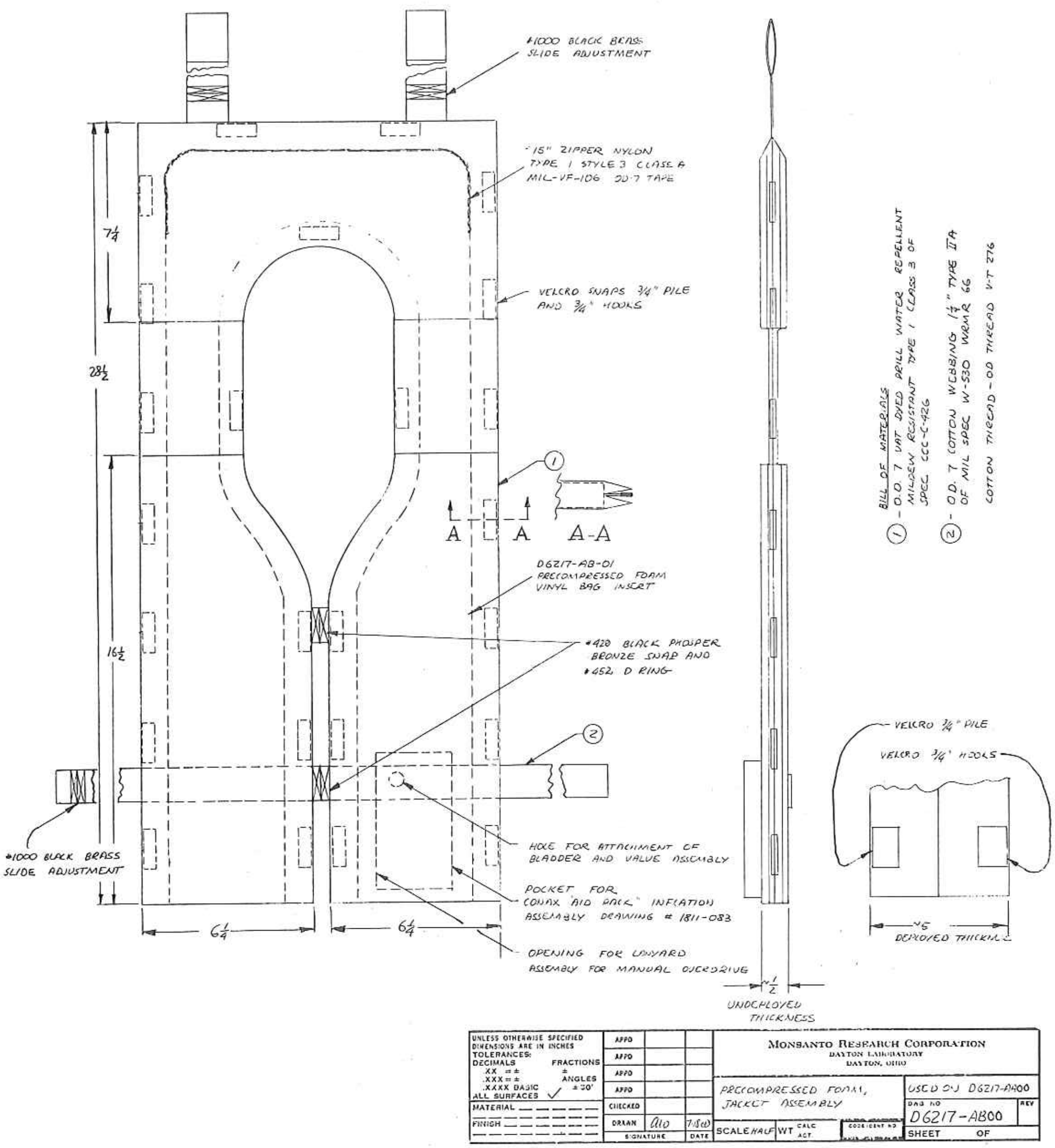


Figure 4. Precompressed Foam Jacket Assembly

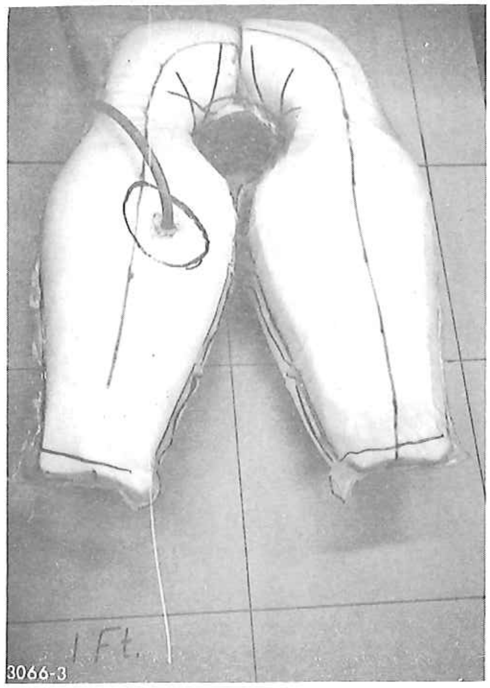
Cloth Carrier

The vinyl bag plus foam assembly is inserted into the jacket assembly. It should be pointed out that upon evacuation, the vinyl bag assembly would be considerably reduced in size. The foam thickness would be reduced from approximately 5.0 inches to 0.5 inches. In addition, considerable shrinkage occurs in the lateral directions. It is estimated that the length and width of the foam will be reduced to approximately 70 percent of their original dimensions. A foam collar is shown in Figures 5 and 6 before and after collapse. The jacket assembly was designed to be worn over the protective armor. A separate means of attachment of this jacket assembly to the man was proposed. No modification of the existing armor assembly would have been necessary. Furthermore, the proposed jacket assembly can be worn by a person not wearing armor.

It is proposed to manufacture the jacket assembly from O.D. 7 vat-dyed type cloth conforming to specification CCC-C426. It is to consist essentially of two layers of cloth folded on the edges of the jacket in an "accordion" type fold. An opening in the back of the jacket provided for the insertion of the vinyl bag assembly into the cloth carrier and is closed by a nylon zipper. Upon insertion of the vinyl bag assembly, the foam would be evacuated. As mentioned previously, this flattened the jacket to approximately 0.5-inch thickness. The sides of the jacket would then be folded in an "accordion" type fold and held in this position by a series of strategically placed Velcro® fasteners. Upon inflation, the Velcro fasteners open allowing the carrier to expand to its fully inflated position with a total jacket thickness of approximately 5 inches. A pocket for the Conax Corporation "Aid Pak" Inflation Assembly is provided in the jacket. It is proposed to attach the carrier assembly to the man wearing armor.

It is proposed to employ the services of Safegard Corporation of Covington, Kentucky for manufacturing prototype cloth carriers. Safegard Corporation is a manufacturer of the commercial flotation equipment and is experienced in producing flotation equipment according to Government specifications.

To provide good flotation and the ability to assume correct altitude in the water, it is absolutely necessary to provide a rigid, secure coupling between the man and a flotation device. To achieve this, it was considered necessary to



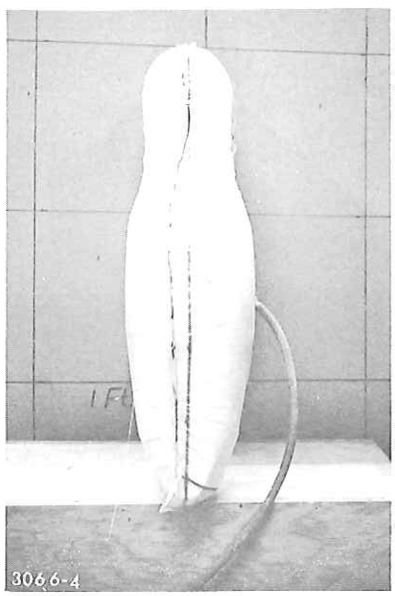


Figure 5. Foam-filled Flotation Collar (deployed)

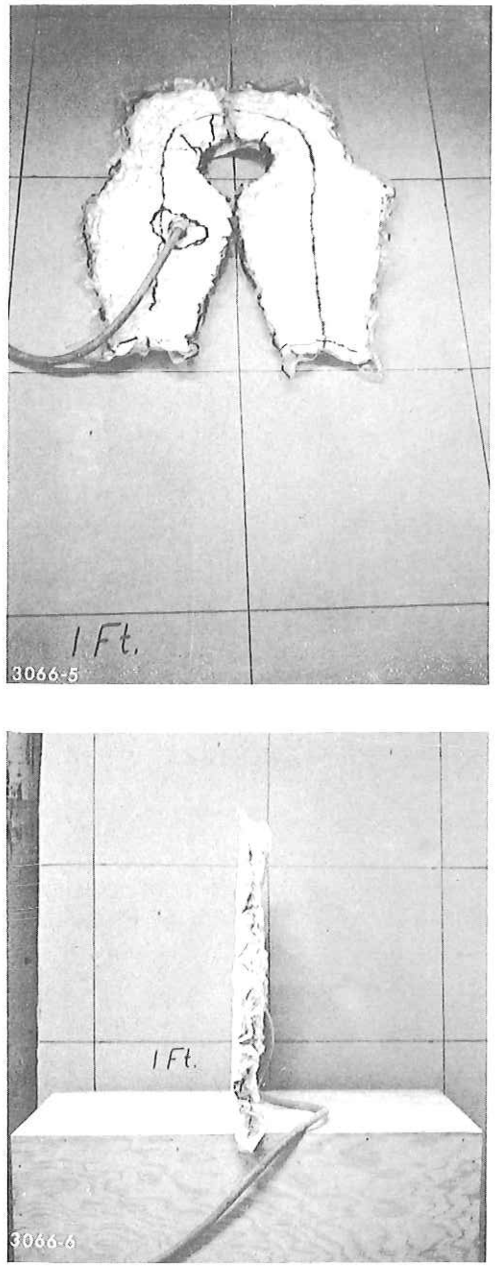


Figure 6. Foam-filled Flotation Collar (collapsed)

securely attach the section of the foam located behind the head to the armor carrier and also provide enough freedom to allow support for the head. It was proposed to achieve this with two adjustable straps located in the back of the jacket and attached to the waist of the carrier. It was believed that the optimum location of the straps and points of attachment would be experimentally determined in Phase 3 of the program.

CO_2 Inflation System

For the precompressed foam inflation system, it was proposed to utilize a Conax Corporation "Aid Pak" automatic and/or manual inflation dual CO_2 cylinder assembly (Figure 7). This unit automatically activates CO_2 cartridges upon contact of the electrical sensing circuit with water. A manual override for the system is also provided. The Conax Corporation "Aid Pak" unit has met U. S. Navy testing procedures and is described in a report by Conax Corporation, "Specifications Inflation Assembly Automatic Manual Life Perserver" No. DS-1811-1. It was considered that this was the most desirable system since it met all the requirements of the precompressed foam system. Also, the system is essentially an off-the-shelf item and no design modifications would be necessary to adapt this activation unit for our purposes. However, it is not a regular production item and its purchase in small quantities made it quite expensive.

The Conax inflation assembly is attached to the inflation valve in the manner described in MIL-L-25370D (USAF) with the necessary modifications to make it compatible with the precompressed foam system.

Overall System

The estimated weight and volume requirements for the proposed system are shown in Table 3. It was believed that a 4-pound weight requirement could be met with this concept. Volume requirement of 48 cu in. could not be met since 130 cu in. of compressed foam will be required. However, it should be emphasized that this volume would have been distributed over a large surface area and thus would not materially add to the bulkiness of the system.

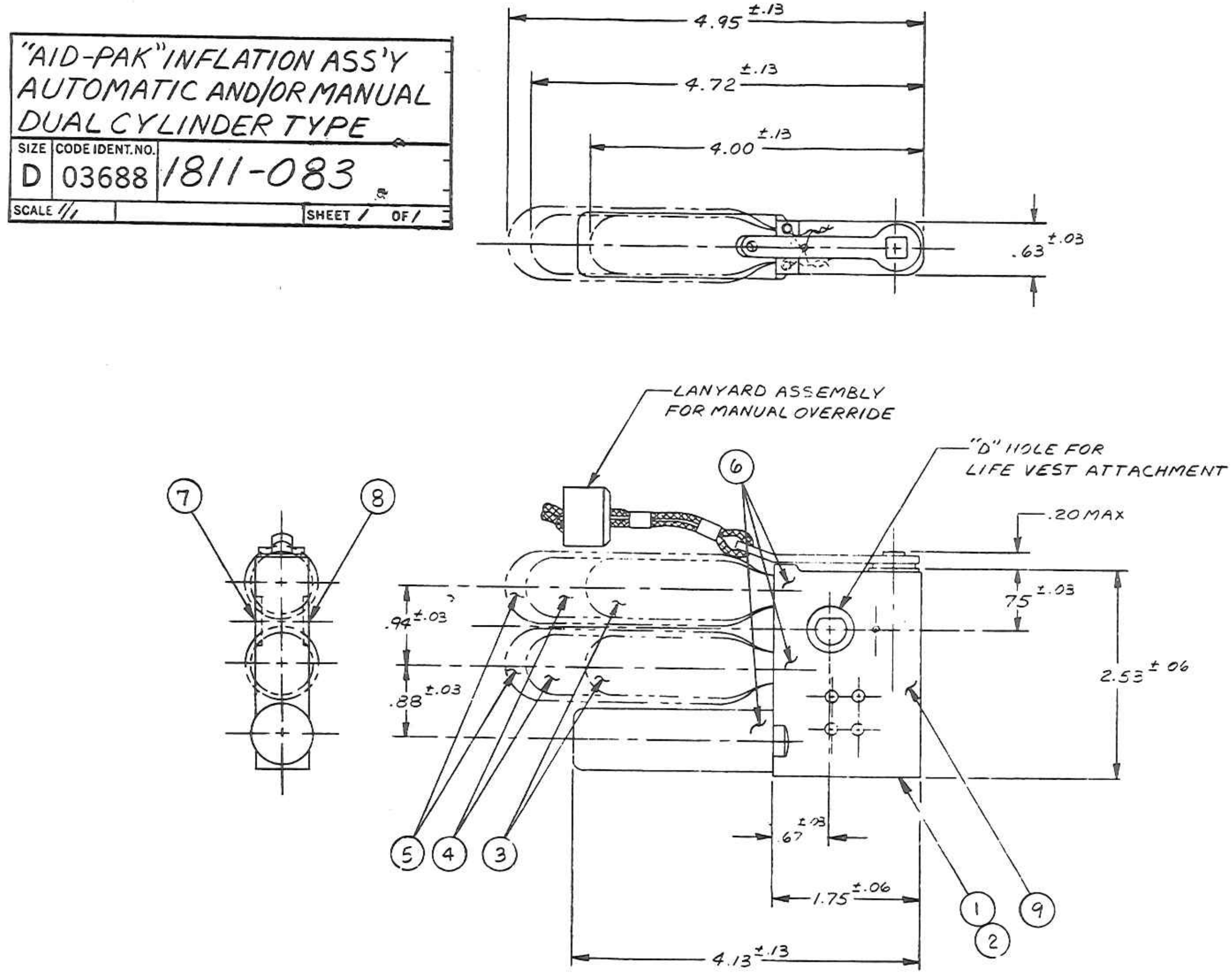


Figure 7. Conax Aid Pak

Table 3

WEIGHT AND VOLUME REQUIREMENTS FOR THE PRECOMPRESSED FOAM SYSTEM

Item	Estimated Vol. (in.^{3})	Estimated Weight (lb)
Conax Corp. "Aid Pack" Assy.	7.0	0.58
Foam and Vinyl Bag Assy. (evacuated)	130.0	1.20
Cloth Carrier Assy.	-	2.00
TOTALS	137.0	3.78

Functioning of Design

The proposed collapsed preformed foam system consisted of a separate carrier assembly worn over the aircrewman armor or over an individual without armor. Appropriate length adjustments in straps is provided for secure fastening of the flotation system to the individual. Upon contact with water the sensing circuit and mechanism in the Conax Corporation inflation assembly activates and punctures the CO_2 cartridges which in turn inflate and expand the compressed foam in three separate compartments. The expanded foam provides flotation as well as support for the head with the foam section located in the back of the neck. The precompressed foam system can be readily returned to original condition by re-evacuation of the vinyl foam containers. This can be also done as a part of a service or maintenance procedure if required. The functioning of the proposed precompressed foam system is simple. It is essentially the same system as that used in the present pneumatic inflation assemblies except that the pneumatic pressure is released into the open-cell foam. This provides a measure of protection in case of damage of the inflation assembly by either snagging and/or projectile penetration. The effect of puncturing the foam envelope while under water prior to or during inflation was not determined.

(c) Fabrication of System (Phase 3)

At the end of the second phase, designs for preformed flexible foam along with two other concepts were submitted. These designs were complete to the extent that detail drawings of all components were on hand.

The concepts and designs in which the flotation system was provided by a separate garment to be worn over the armor and its carrier, was not accepted by the technical personnel at Natick Laboratories. The basis for rejection was that the flotation system had to be an integral part of the armor plus carrier.

The problem of mounting any of the foam systems on the already existing carrier was considerably more difficult than providing a separate piece of flotation equipment. This rejection required repetition of almost the entire second phase of this program superimposed on the third phase.

In the new design, the precompressed foam flotation jacket consists of a cloth cover sewn on the present carrier, the necessary foam packaged in hermetically sealed vinyl envelopes, a gas distribution system, and two automatically actuated carbon dioxide cylinders.

Cloth Carrier

The cloth cover is permanently mounted on the armor carrier and closed by a zipper around its perimeter. The cover is used to contain the compressed foam and the gas distribution system.

Sufficient material is used in the cover so that the expanded foam barely fills it. Excess cloth is accommodated in accordion pleats when the foam is in the collapsed condition. These pleasts are held closed prior to inflation by either strips or tabs of Velcro or by snaps. A pocket is provided on the right front side for the carbon dioxide bottles and automatic/manual actuator.

The collar is broken at the right shoulder to permit easy removal of the flotation gear, armor carrier, and armor. The entire assembly is closed at the sides at waist level by two bands of Velcro pulled through D rings and fastened at the back.

Figures 8, 9, and 10 are front, side, and rear views of the carrier plus the flotation system mounted on a mannequin.

The principal advantage of this carrier is that it is relatively simple and leaves the front area open and uncluttered by pressure bottles and tubes. This reflects the overall simplicity of the precompressed foam system.

Four jackets or covers of this jacket were made. Two had the pocket for the carbon dioxide bottles mounted on the foam envelope, which was not acceptable. Two later versions had the pocket for the bottles moved well to the side. One early version had the accordion pleats closed by low strength snaps while two others were closed by strips of Velcro around the perimeter of the jacket. The fourth jacket was closed by tabs of Velcro.(R)

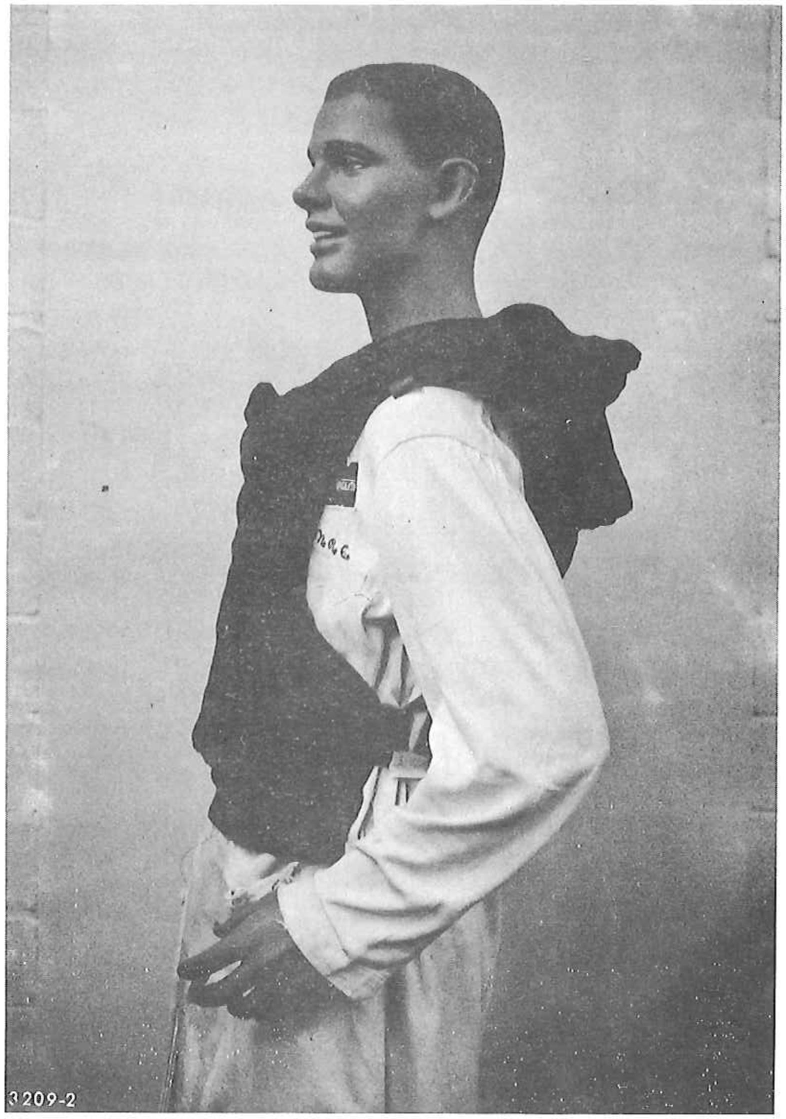


Figure 8. Side View Pre-Compressed Foam Cover Plus Carrier

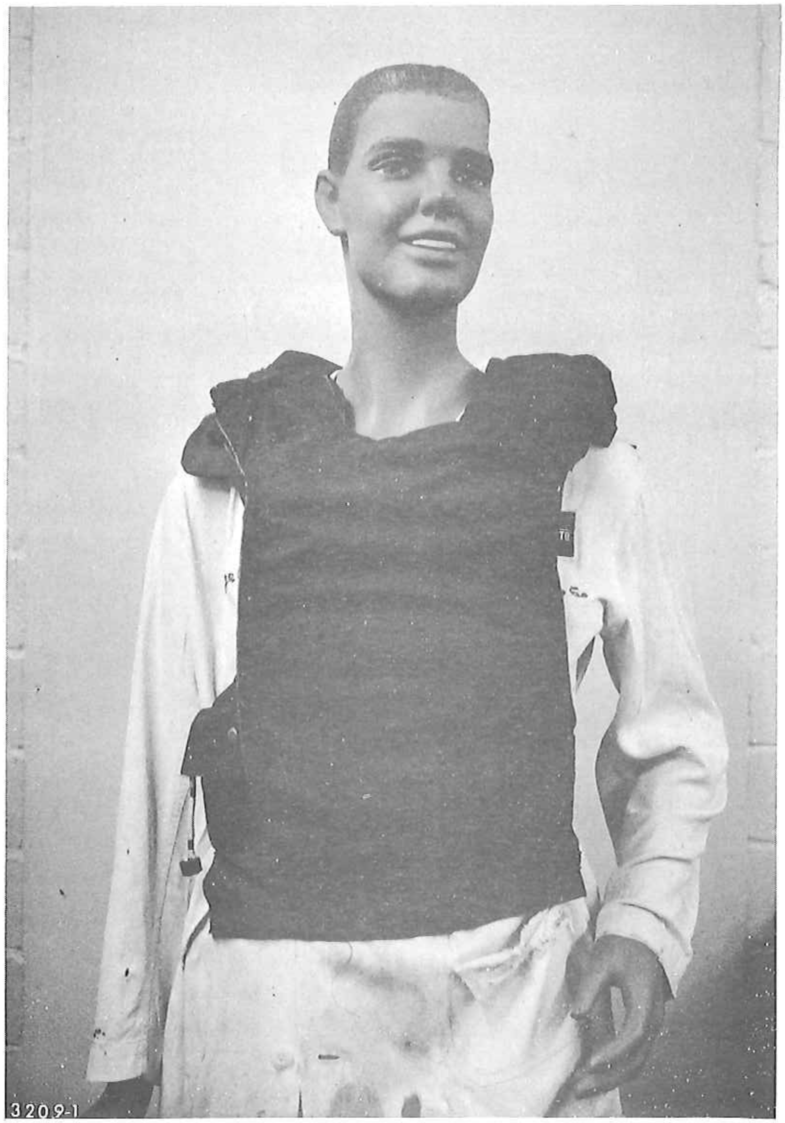


Figure 9. Front View Pre-Compressed Foam Cover Plus Carrier

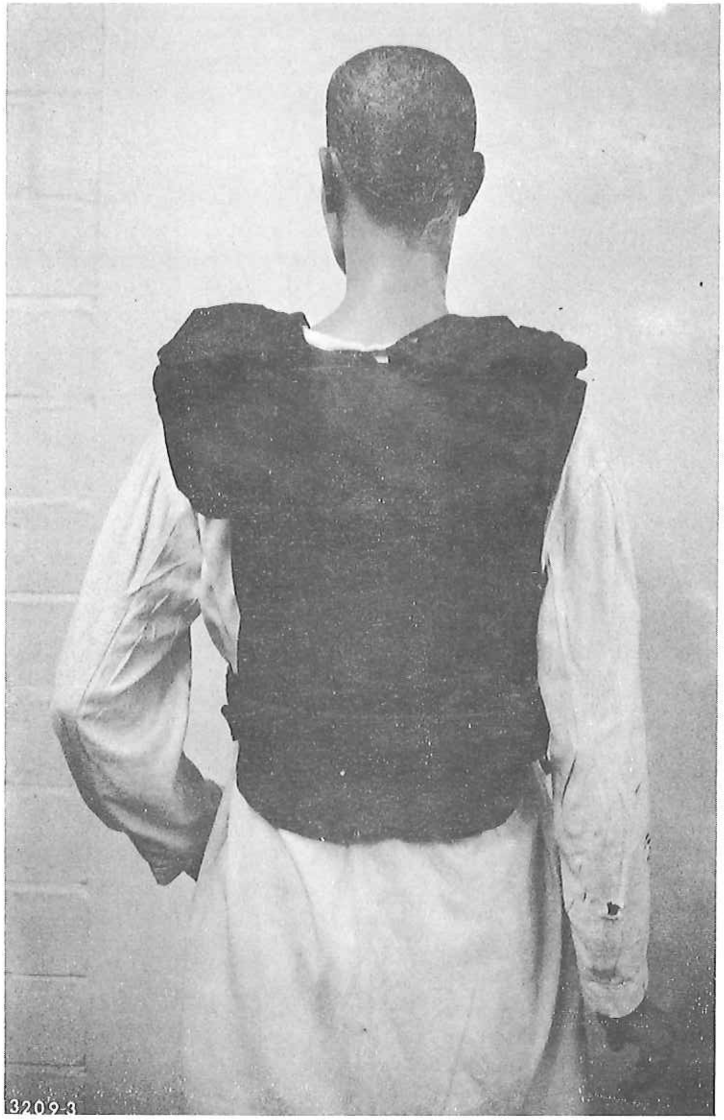


Figure 10. Rear View Pre-Compressed Foam Cover Plus Carrier

Gas Inflation System

The gas supply system for the precompressed foam design consists of the automatic water sensing and actuating mechanism, CO_2 supply cylinders, and the gas manifold and the distribution system.

Based on the original requirement that an automatic inflation system was necessary, work was directed towards development and/or selection of a suitable inflation assembly. It was determined early in the project that an automatic CO_2 actuating system developed by the Conax Corp. of Buffalo, N.Y., was readily available.

The Conax Corporation automatic/manual "Aid Pak" inflation assembly consists, essentially, of a water sensing and actuating circuit, battery power supply, pyrotechnic CO_2 cartridge piercing device, two 16-gram CO_2 cylinders, and a manual override actuating mechanism. A photograph of the unit is shown in Figure 11. Upon the total immersion in water, the water-sensing mechanism is actuated and the battery supplies the necessary current to fire the pyrotechnic cartridge. The released energy then in turn actuates a CO_2 cartridge piercing mechanism, thus releasing the CO_2 gas. The total weight of the "Aid Pak" is approximately 270 grams.

The "Aid Pak" assembly is connected to the precompressed foam packages through a simple gas distribution system. Six precompressed flotation foam blocks were utilized to provide flotation. Each block of foam was connected through a plastic distribution tube to a six-port manifold, which in turn was connected to the "Aid Pak" assembly. Upon the actuation of the CO_2 cylinders, gas is first directed to the common manifold and then through plastic tubes to each individual sealed foam block. Each gas distribution tube ends in the center of a foam block. This facilitates rapid and optimum dispersion of the CO_2 gas into the block. Some problems were encountered in positioning of the gas distribution tubing inside the armor carrier. The tubing tended to shift inside the carrier, which resulted in shifting of the foam blocks and thus poor flotation distribution. This difficulty can be corrected by making the gas distribution system an integral part of the armor carrier.

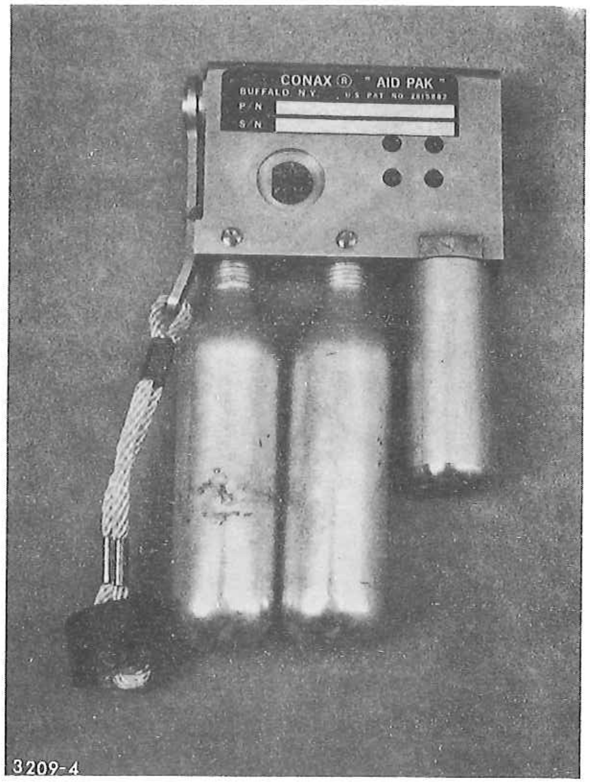


Figure 11. Conax Aid Pak (water actuated CO_2 supply)

(3) Test Program

Testing was carried out in each of the three phases of the program.

(a) Test Program (Phase 1)

Experiments using a 173-lb man wearing a swimming suit and aircrew armor indicated that approximately 0.34 cu ft or 19 lb of positive buoyancy force was required to support the subject with his head above the water. It was experimentally determined that elevation of any part of the shoulders above the water is unnecessary; it does not make a subject more comfortable and places unduly stringent requirements on the flotation system.

Positioning of the flotation material on the body is very critical. The optimum configuration appears to be approximately 66-75% of the flotation material on the upper part of the chest and 34-25% of the material around the back of the head. This configuration provides a good support for the head and has excellent stability in the water. Repeated attempts were made to float a subject with such a flotation gear configuration with the face down. The subject was quickly and automatically inverted into upward position with no effort to do so on his part. It appears that no flotation is necessary on the back armor plate.

Figure 12 shows a floating man naturally supported by a 0.34 cu ft block of foam on the chest and a 0.16 cu ft piece of foam fastened around the back of the neck. Figure 13 shows the same man and foam system righting himself after being made to float face down in the water.

(b) Test Results (Phase 2)

No flotation tests on a man were conducted in the Phase 2 work. However, tests to determine the effect of compression set were conducted (2, C, 5, a) and water absorption by damaged packages of flexible foams (2, C, 5, b).

(c) Test Results (Phase 3)

Testing of the armor carrier plus flotation equipment was done in both air and water.

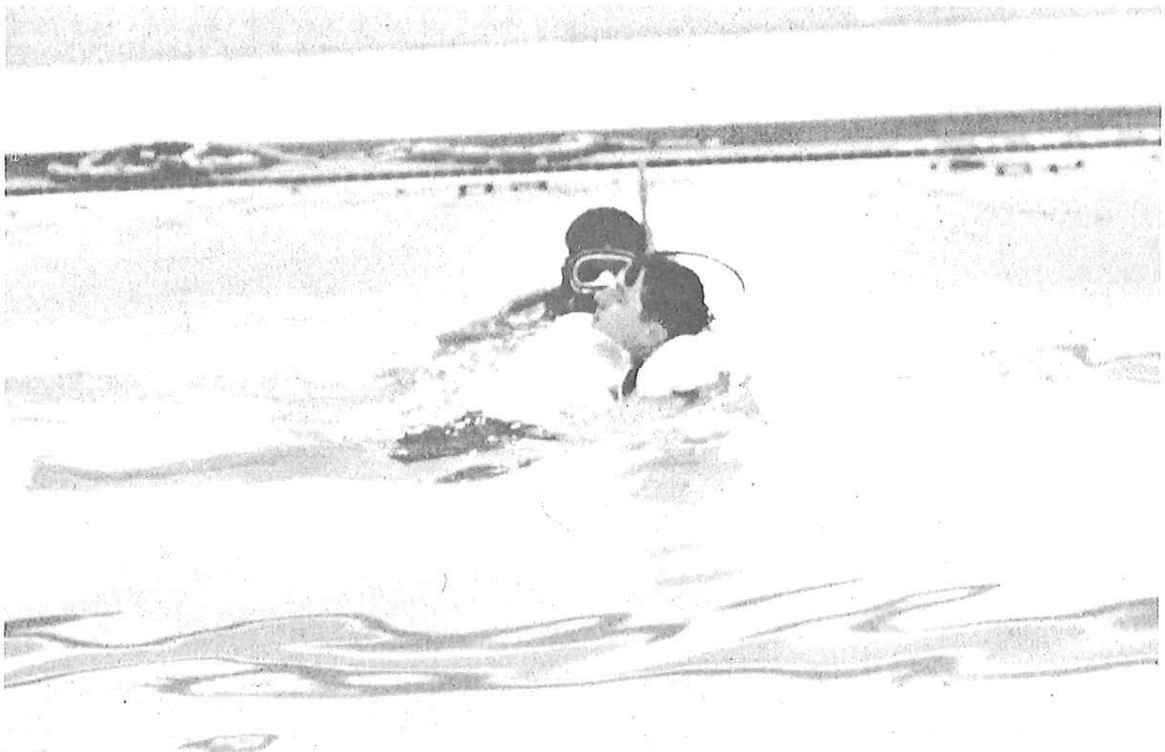


Figure 12. Man Wearing Armor Floating in Normal Position Supported by Foam

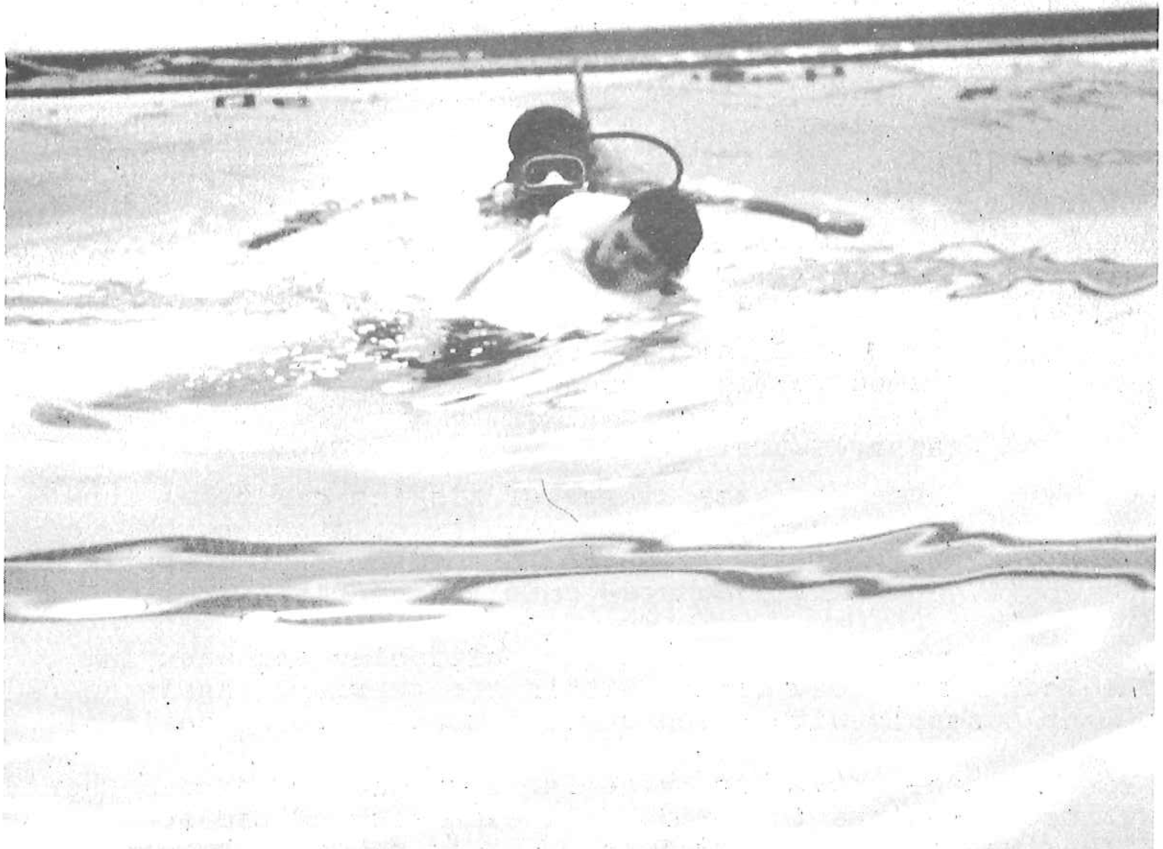


Figure 13. Man Wearing Foam and Armor Righting Himself After Being Made to Float Face Down

Testing in air was done to determine how well the flotation system functioned and to pinpoint problem areas. All tests were run on a mannequin with armor carrier and flotation system in place. Actuation of the carbon dioxide flotation system was by manual means (Knapp-Monarch actuating mechanism plus two 16-gm gas cartridges). Inflation was always rapid and essentially complete in less than 5 seconds. The results of this work showed the following:

- Vacuum tight systems could be built.
- Inflation was very rapid upon actuation.
- Gas distribution tubes had to be secured by clamps to their connections to prevent blow off of the tubes during the initial surge of gas pressure.
- There was some danger of kinking gas tubes during assembly. These results pointed out the desirability of having the distribution system permanently mounted into the carrier.

Improvements are needed in positioning and securing the individual foam blocks within the carrier. Again, permanent assembly within the carrier appears to be desirable.

The type of Velcro used for securing the excess fabric was too tenacious to permit full expansion of the foam. Either weaker Velcro or less of it is needed. Alternatively, weak snaps could be used.

Despite these difficulties in selecting materials and in design, the tests in air indicated the precompressed foam was a feasible system for providing flotation.

Both fully automatic and manually actuated tests of the precompressed foam system were run in water. They were conducted with a man wearing armor, the regular carrier, and its flotation gear. He was fully clothed and wearing a flight helmet plus boots. Figures 14 and 15 show the man prior to the tests.

With both manual and automatic actuation of the gas cylinders, flotation was provided for the man within a short time ($\sim$5 seconds). The subject floated in the face-up position. He reported it was not possible to float in the face-down attitude.

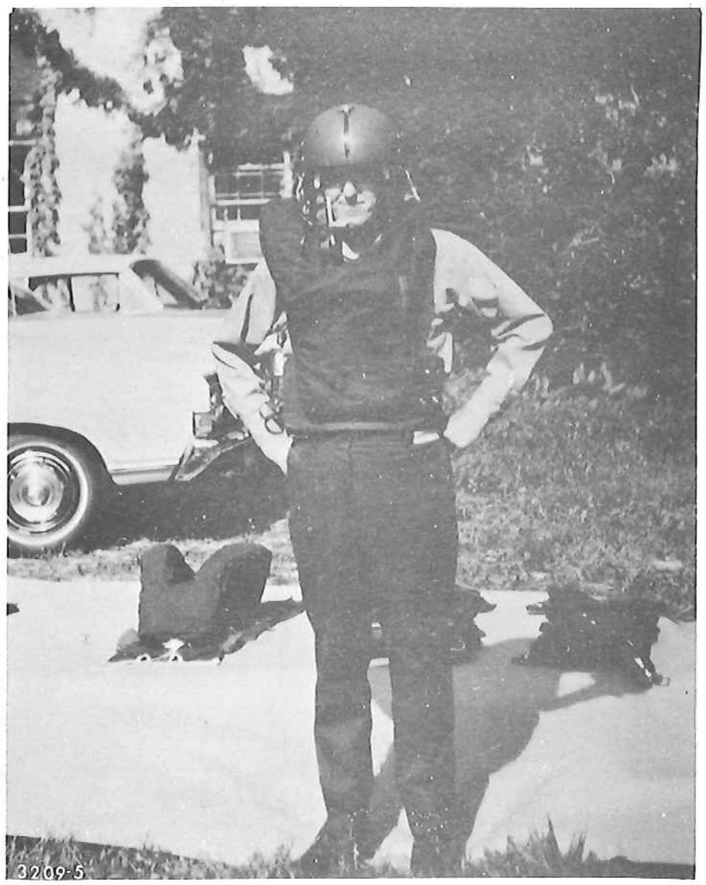


Figure 14. Front View of Man Wearing Body Armor and Pre-Compressed Foam System

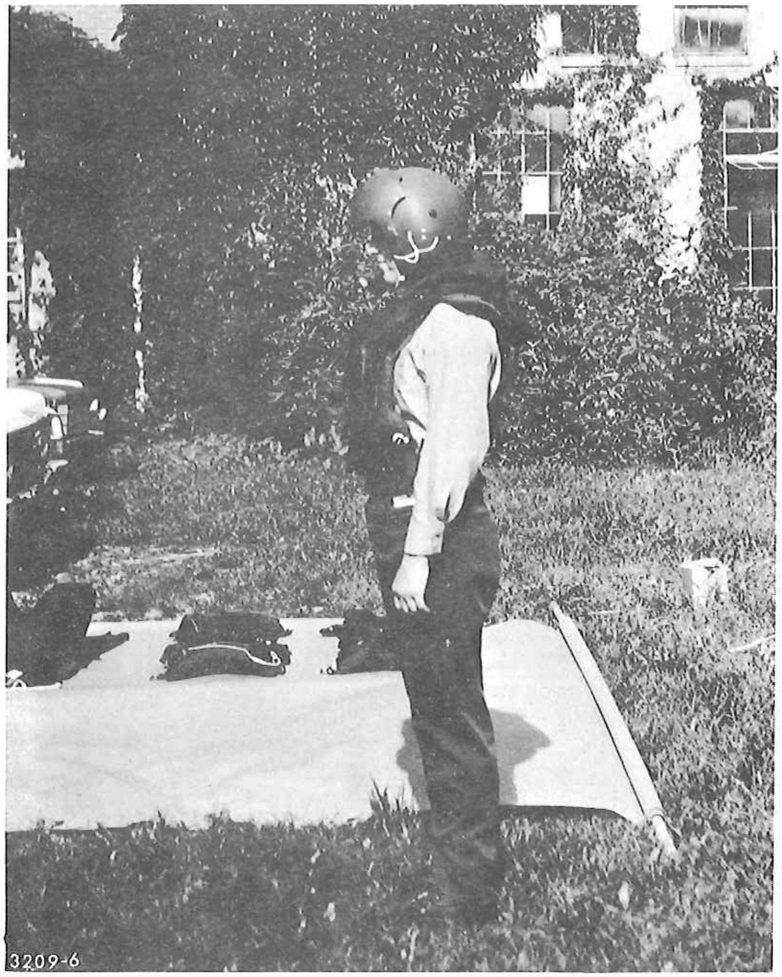


Figure 15. Right Side View of Man Wearing Body Armor and Pre-Compressed Foam System

During the early tests it became obvious that the flotation blocks over the shoulder were too long, permitting the collar to float too high up on the head. This made it difficult for the man to keep his head within the collar. The foam blocks going over the shoulder were shortened for subsequent tests. Also, the side closure at the right shoulder had a tendency to gap apart. This gave a loose fit to the collar on the right side. Figure 16 shows the man floating with this system.

The results of these tests show that precompressed foam is a dependable, fast-acting flotation system which is well advanced toward being a practical flotation system.

(4) <u>Advantages of Using Preformed Flexible Foams</u>

Preformed flexible foam has the following advantages for use in a compact, deployable flotation system.

- Its function for deployment depends on a property inherent in flexible foams, namely, their natural resilience. Because of this, such a system is relatively simple and foolproof.

- Flotation depends on foams that are premanufactured in a plant under controlled conditions. As such, these foams would be superior in properties to foams that are made *in situ*.

- The foam is always present to provide flotation; all that is necessary is to inflate the envelope and foam with gas.

- The preformed flexible foam, being open-celled, compresses easily under vacuum. This provides for ease of storage, and for making a compact flotation system.

- Precompressed foam has some shock-absorbing properties. As such it can be made to cushion the upper edge of the armor and thus help to reduce chin and neck injuries.

- The foam is relatively insensitive to environmental temperature conditions.

- The foam is position insensitive.

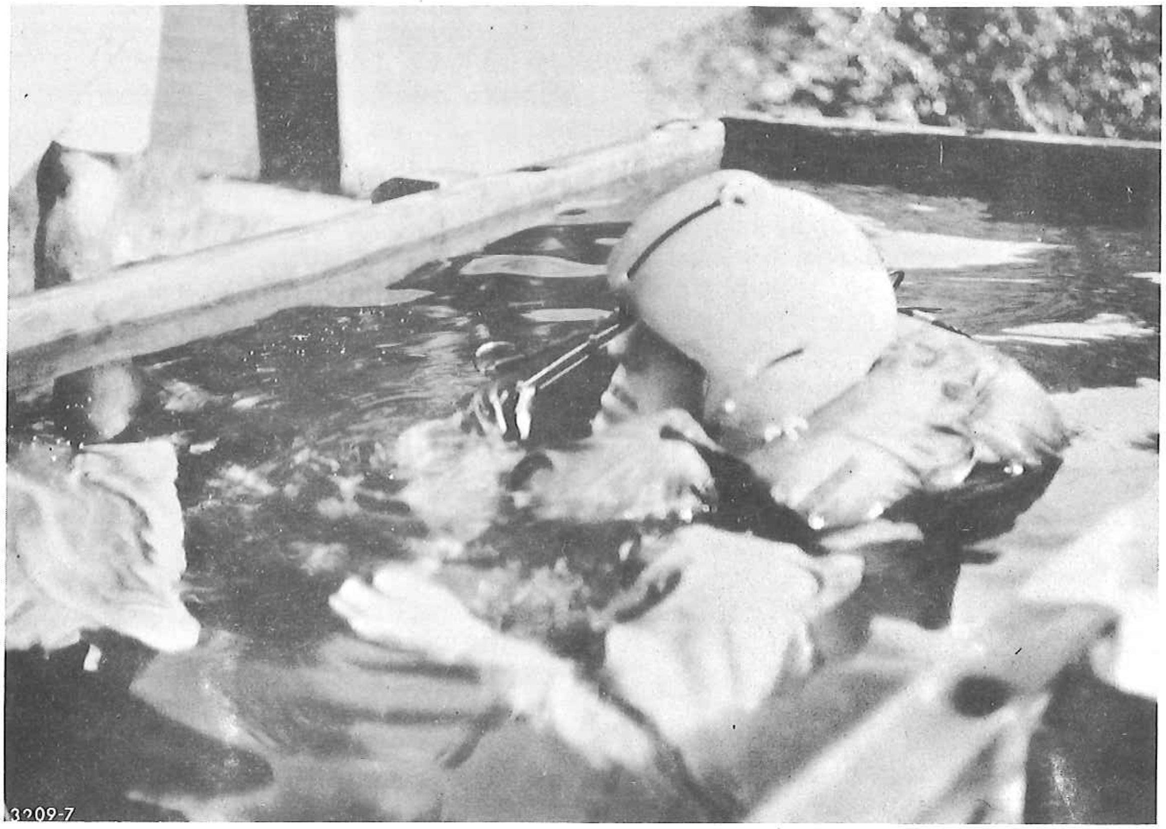


Figure 16. Man Wearing Body Armor Floating in Tank

(5) Possible Disadvantage of Preformed Flexible Foams

Preformed flexible foams have two possible disadvantages as a flotation material (1) the foam may take a permanent set when compressed to 10% of its original volume for long periods of time; and (2) flexible foams, which are necessary if the foam is to collapse to small volume, are open-celled. As such the possibility exists that the foam will imbibe water and thus lose its buoyancy. The danger of exposure to water exists if the protective and air-tight envelope around the foam should be damaged.

Tests were run to determine if these problems were serious and if they might be overcome.

(a) Permanent Set of Compressed Flexible Foams

Samples of four commercial foams were tested for compression set when stored in the 90% compressed condition at 130°F. Four conditions of storage were used as follows:

- Uncoated foam stored in air
- Uncoated foam stored in vacuum
- Zinc stearate-coated foam stored in air
- Zinc stearate-coated foam stored in vacuum

Uncoated foams were in the as received condition. Coated foams had been treated with a slurry of zinc stearate suspended in hexane. The foams were made to imbibe the slurry by alternately collapsing and allowing the foam to expand while submerged in the slurry. After the foams were saturated with slurry they were suspended in air and the bulk of the hexane plus zinc stearate allowed to drain from the foam. After draining the foams were passed through a wringer to remove the last of the liquid. They were then air dried.

All foam samples were enclosed in a heat sealed vinyl envelope. The envelopes of the samples that were to be aged in air were sealed completely with the fully open foam inside them. The envelopes of the samples to be aged in vacuum were sealed completely but were provided with a short tube for evacuation of the foam.

The foam samples, which were to be aged in air, were collapsed to 10% of their original thickness by placing them between metal plates and compressing them using C-clamps to

force the plates together. The collapsed samples contained the air that was originally in the sealed envelope.

The specimens which were to be aged in vacuum had the air evacuated from their envelope using a vacuum pump. As the air was withdrawn the foam collapsed to less than 10% of the original thickness. The tube connected to the envelope was then closed with a clamp.

All samples were placed in an oven and initially aged at 130°F for 28, 56, and 84 days. At the end of each period the restraints (either plates in the case of air aged samples, or vacuum in the case of evacuated samples) were removed and the samples allowed to open. The samples were observed for rapidity of opening. All samples had opened essentially as much as they were going to open in the first minute after removal of the restraints. Measurements were made 30 minutes after the samples had opened so that the samples could cool to room temperature.

The results of these initial tests are reported in Tables 4, 5, 6, and 7.

Compression set is recorded as:

$$\% \text{ of original thickness, } C_t = \frac{t_o - t_f}{t_o} \times 100$$

and

$$\% \text{ of original deflection, } C_d = \frac{t_o - t_f}{t_o - t_s} \times 100$$

Where: t_c = original thickness

t_s = thickness of spacer bar used in clamping of deflection device, or the evacuated sample

t_f = final thickness of test specimen after removal of restraints (measured 30 min after release).

The data for 84 days of storage at 130°F indicate that permanent set is not a problem for the foams tested when they are coated with zinc stearate and, more importantly, when

Table 4

COMPRESSION TEST ON FOAMS

Conditions:

Temperature	130°F
% Compressed	90%
Foam Treatment	None
Storage	In Air

Foam	Sample No.	Compression Set (%) after storage					
		After 28 Days		After 56 Days		After 84 Days	
		C_t	C_d	C_t	C_d	C_t	C_d
International Foam 1553	4	13.58	15.06	15.75	17.47	18.31	20.31
	5	9.29	10.32	10.29	11.43	12.59	13.98
	6	10.40	11.56	11.90	13.22	13.90	15.44
	Average	11.09	12.31	12.65	14.04	14.93	16.58
General Tire and Rubber P-137	4	14.60	16.14	17.18	18.99	17.65	19.51
	5	43.99	48.63	35.50	39.24	35.34	39.03
	6	--	--	--	--	--	--
	Average	29.30	32.38	26.34	29.12	26.48	29.27
B. F. Goodrich UU-34	10	7.42	8.25	7.42	8.25	9.13	10.14
	11	5.12	5.72	4.91	5.48	6.37	7.12
	12	6.20	6.88	6.20	6.88	7.68	8.52
	Average	6.25	6.95	6.18	6.87	7.73	8.59
A.R.P. Co. Foam 216 E.	16	10.77	11.99	14.13	15.72	15.04	16.74
	17	11.58	12.90	13.93	15.53	15.98	17.81
	18	10.28	11.45	12.33	13.75	13.67	15.23
	Average	10.88	12.11	13.46	15.00	14.90	16.59

Table 5

COMPRESSION TEST ON FOAM

Conditions: Temperature 130°F
% Compressed 90%
Foam Treatment None
Storage In Vacuum

Foam	Sample No.	Compression Set (%) after storage: After 28 Days C_t	After 28 Days C_d	After 56 Days C_t	After 56 Days C_d	After 84 Days C_t	After 84 Days C_d
International Foam 1553	1	4.77	5.28	3.51	3.88	4.09	4.53
	2	3.91	4.33	2.25	2.49	3.71	4.12
	3	6.48	7.20	6.18	6.87	8.18	9.08
	Av.	5.05	5.60	3.98	4.41	5.33	5.91
General Tire and Rubber P 137	1	6.54	7.22	7.48	8.25	8.50	9.38
	2	4.74	5.24	6.45	7.12	7.11	7.85
	3	5.63	6.21	6.85	7.56	7.50	8.28
	Av.	5.64	6.22	6.93	7.64	7.70	8.50
B.F. Goodrich UU 34	7	4.32	4.80	2.61	2.90	4.12	4.58
	8	4.93	5.49	3.22	3.58	4.53	5.04
	9	4.10	4.56	2.40	2.67	3.30	3.67
	Av.	4.45	4.95	2.74	3.05	3.98	4.43
A.R.P. Co. Foam 216 E.	13	6.52	7.27	7.45	8.31	8.90	9.93
	14	6.13	6.83	7.06	7.86	8.18	9.11
	15	6.34	7.06	6.95	7.74	8.38	9.34
	Av.	6.33	7.05	7.15	7.97	8.49	9.46

Table 6

COMPRESSION TEST ON FOAM

Conditions: Temperature 130°F
% Compressed 90%
Foam Treatment Zinc Stearate Coated
Storage In Air

Foam	Sample No.	Compression set (%) after storage: After 28 Days C_t	After 28 Days C_d	After 56 Days C_t	After 56 Days C_d	After 84 Days C_t	After 84 Days C_d
International Foam 1553	4	7.62	8.45	7.14	7.91	8.99	9.97
	5	7.86	8.71	7.86	8.71	9.14	10.13
	6	8.54	9.48	8.14	9.04	9.93	11.03
	Av.	8.01	8.88	7.71	8.55	9.35	10.38
General Tire and Rubber P 137	10	10.62	11.75	12.36	13.68	13.32	14.74
	11	10.26	11.33	12.16	13.43	12.92	14.27
	12	12.04	13.33	13.78	15.25	14.93	16.52
	Av.	10.97	12.14	12.77	14.12	13.72	15.18
B.F. Goodrich U.U. 34	10	12.36	13.76	12.36	13.77	14.40	16.04
	11	8.75	9.76	8.55	9.53	10.81	12.06
	12	12.61	14.03	13.22	14.70	15.44	17.17
	Av.	11.24	12.56	11.38	12.67	13.55	15.09
A.R.P. Co. Foam 216 E	16	10.61	11.82	9.89	11.02	12.46	13.89
	17	11.10	12.36	10.59	11.79	12.83	14.29
	18	11.10	12.36	10.39	11.56	12.83	14.29
	Av.	10.94	12.18	10.29	11.46	12.71	14.16

Table 7

COMPRESSION TEST ON FOAM

Conditions:
Temperature 130°F
% Compressed 90%
Foam Treatment Zinc Stearate Coated
Storage In Vacuum

Foam	Sample No.	After 28 Days C_t	After 28 Days C_d	After 56 Days C_t	After 56 Days C_d	After 84 Days C_t	After 84 Days C_d
		Compression Set (%) after storage					
International Foam 1553	1	2.77	3.07	-1.48	-1.65	-0.69	-0.77
	2	2.52	2.81	-1.01	-1.12	-0.61	-0.67
	3	2.09	2.32	-1.69	-1.88	-0.99	-1.10
	Av.	2.46	2.73	-1.39	-1.55	-0.76	-0.85
General Tire and Rubber P 137	7	4.26	4.71	3.77	4.18	3.97	4.39
	8	4.51	4.98	3.99	4.24	4.12	4.56
	9	5.30	5.86	4.82	5.33	5.01	5.54
	Av.	4.61	5.18	4.19	4.58	4.37	4.83
B.F. Goodrich U.U. 34	7	8.75	9.76	4.22	4.71	5.15	5.74
	8	4.67	5.21	1.56	1.74	2.08	2.32
	9	7.79	8.68	3.69	4.11	4.61	5.14
	Av.	7.07	7.88	3.16	3.52	3.95	4.40
A.R.P. Co. Foam 216 E	13	6.80	7.58	2.57	2.87	4.12	4.59
	14	6.81	7.51	2.81	3.12	4.01	4.45
	15	6.63	7.37	2.31	2.57	3.51	3.91
	Av.	6.75	7.51	2.56	2.85	3.88	4.32

they are stored in a vacuum. The reasons for the slight growth of International Foam 1553 as indicated by a negative permanent set are not known at the time. Any one of the foams tested would be suitable for use in a life jacket on the basis of resistance to permanent set.

At the end of the first 84 days of testing it became apparent that those samples of foams which had been treated with zinc stearate and that were stored compressed in a vacuum were of the most interest. Accordingly, these samples (zinc stearate-treated and stored in evacuated packages) were returned to test. This was a continuous test at 130°F for 395 days. Again, the samples were compressed to 10% of their original thickness. The results for the entire test period are given in Table 8.

The results show that none of the foams take a serious amount of compression set even after prolonged storage. Recovery was rapid after release, being an estimated 90% complete after only 10-15 seconds. Measurements were made 30 minutes after release. All of these foams showed good recovery properties with the International Foam 1553 being the best of the four. The foam used in the models built contained General Tire and Rubber F137, which was the poorest performer for this purpose of the foams tested. It was chosen early in the program because of earlier experience with it in a similar application. It is apparent that the International foam would have given even better performance. The long term aging data were not available at the time a selection of foam for the models had to be made.

The results of the work indicates that compression set during storage would probably not be a serious problem in using precompressed foams in life jackets or other flotation gear.

(b) Water Absorption by Flexible Foams

Sample slabs of F137 Foam approximately 2 x 2 x 12 inches were tested for flotation properties. Foams were tested with a variety of interior and exterior treatments. Results of this work are summarized in Table 9. Zinc stearate and Hydrophobol (Geigy Chemical Co.) are both water repellents. Polyvinyl alcohol (PVA) solutions were applied to the surface of selected foams. PVA is a water-soluble and swellable polymer; it was hoped that swelling would provide a self-sealing coating

Table 8

COMPRESSION SET TEST ON FOAM

Conditions: Temperature 130°F
% Compressed 90%
Foam Treatment Zinc Stearate Coated
Storage In Vacuum

Foam	Compression Set (%) After Storage							
	After 28 days		After 56 days		After 84 days		After 479① Days	
	C_t②	C_d③	C_t	C_d	C_t	C_d	C_t	C_d
International Foam 1553	2.5	2.7	-1.4	-1.6	-0.8	-0.9	3.4	3.7
General Tire and Rubber P137	4.6	5.2	4.2	4.6	4.4	4.8	11.3	12.5
B. F. Goodrich U.U. 34	7.1	7.9	3.2	3.5	4.0	4.4	10.0	11.1
A.R.P. Co. Foam 216E	6.8	7.5	2.6	2.9	3.9	4.3	10.5	11.7

① Final 395 days were continuous at 130°F.

② and ③ C_t = % of original thickness $= \left(\frac{t_o - t_f}{t_o}\right) 100$

C_d = % of original deflection $= \left(\frac{t_o - t_f}{t_o - t_s}\right) 100$

t_o = original thickness of test specimen
t_f = final thickness of test specimen after release
t_s = thickness of compressed sample

Table 9

RESULTS OF FLOTATION TESTS

Test No.	Covering	PVA Solution Coating on Foam	Foam Treatment	Condition of Test: Floating	Condition of Test: Knife Cuts	Approx. Loss of Buoyancy, %
1	None	No	No	On surface	-	0.8
2	None	No	Zinc Stearate	On surface	-	0.2
3	None	No	Hydrophobol	On surface	-	0.2
4	None	No	Hydrophobol	On surface	-	6.0
5	None	No	Hydrophobol	On surface	-	0.2
6	Vinyl film	No	None	On surface	On bottom	1.3
7	Vinyl film	No	Zinc Stearate	On surface	On bottom	0.8
8	Vinyl film	Yes	None	On surface	On bottom	3.0
9	Vinyl film	Yes	Zinc Stearate	On surface	On bottom	1.0
10	Vinyl film	No	Hydrophobol	On surface	On bottom	2.0
11	Vinyl film	No	Hydrophobol	On surface	On bottom	3.0
12	Vinyl Solution	No	None	On surface	On bottom	3.0
13	Vinyl Solution	No	Hydrophobol	On surface	On bottom	9.0
14	Vinyl Solution	No	Hydrophobol	On surface	On bottom	32.0
15	None	No	None	Submerged	-	60.0
16	None	No	Zinc Stearate	Submerged	-	35.0
17	None	No	Hydrophobol	Submerged	-	65.0
18	Vinyl Film	No	None	Submerged	On bottom	3.0
19	Vinyl Film	No	Zinc Stearate	Submerged	On bottom	2.0
20	Vinyl Film	Yes	None	Submerged	On bottom	4.0
21	Vinyl Film	Yes	Zinc Stearate	Submerged	On bottom	2.0
22	Vinyl Film	No	Hydrophobol	Submerged	On bottom	1.0
23	Vinyl Film	No	None	Submerged	On top and bottom	78.0
24	Vinyl Film	No	Zinc Stearate	Submerged	On top and bottom	38.0
25	Vinyl Film	Yes	Zinc Stearate	Submerged	On top and bottom	29.0
26	Vinyl Film	No	Hydrophobol	Submerged	On top and bottom	65.0
27	None	No	Hydrophobol	Submerged	-	83.0
28	None	No	Hydrophobol	Submerged	-	74.0
29	Vinyl Film	No	Hydrophobol	On surface	On top and bottom	95.0
30	Vinyl Solution	No	None	On surface	On top and bottom	7.0
31	Vinyl Solution	No	Hydrophobol	On surface	On top and bottom	83.0
32	Vinyl Solution	No	Hydrophobol	On surface	On top and bottom	83.0

to the foam. Certain foams (Nos. 13, 14, 30, 31, and 32 in the table) were coated on their exterior with a solution of vinyl resin in tetrahydrofuran. This formed an integral skin of polymer on the foam. Vinyl film was adhered to other foams using Thixon XAS 138 adhesive (Dayton Chemical Products Laboratories).

These foams were tested under four conditions:

- Foam floating on the surface with a slit on the underside.
- Foam submerged with a slit on the underside.
- Foam submerged with a slit on both the top and bottom
- Foam floating on the surface with a slit on top and bottom.

Hydrophobol was difficult to apply. Because of this and other reasons it was dropped from further consideration.

The data also showed that a single hole in the foam envelope below the waterline resulted in only a slight loss of buoyancy during a six-hour period. This applied whether the foam is floating on the surface or submerged.

Slits on both the bottom and top of a submerged foam resulted in about a 1/3 loss in buoyancy over a six-hour period when the foam was treated with zinc stearate. This applied to foams with and without a solution coating of polyvinyl alcohol.

Coating the foam with a vinyl solution supplied an integral skin on the foam and offered advantages in assembly over a separate vinyl skin.

In summary, a single hole below the water did not result in serious loss of buoyancy in foams with a vinyl skin. Foams with two holes in the vinyl skin, one in the top and the other in the bottom lost 1/3 of their buoyancy in six hours.

In evaluating these results, it must be remembered that loss in buoyancy is spread over a six-hour period. This is not nearly so catastrophic as what occurs in an air-filled jacket, where a small hole can result in immediate loss of flotation.

Furthermore, by compartmenting the foam in the actual flotation jacket, the loss of buoyancy in any one compartment results in only a small loss for the total system.

Thus, in a jacket with three equal-size compartments, extensive damage (2 holes) to one results in a 1/3 loss of buoyancy in that compartment, but only a 1/9 loss for the system as a whole.

(6) Summary of the Use of Preformed Flexible Foam

The work on using flexible foams successfully showed that an acceptable flotation system could be made. The system was compact in the stored condition. It was light in weight, and the CO_2 supply system could be moved well off to the side where it would cause little or no interference. The entire system did not add much to the bulk of the present armor plus carrier.

The foam flotation system deployed rapidly when the carbon dioxide cylinder valve was operated either manually or automatically on contact with the water. The flotation system furnished a good degree of flotation and maintained a man in the face-up position when in the water.

The first precompressed foam jackets showed certain weakness in design that needed correction if subsequent items were to be made. They were:

- The Velcro fasteners were too strong to be readily opened. They constrained the foam and prevented full opening. It appeared likely that this deficiency could be easily corrected by using Velcro of a lower tenacity or by using low strength snaps. The one jacket made with snaps opened much more easily.
- The problem of excess material in the cover is one that needs work. The items currently built were hand-made. As a consequence the foam blocks used were cut out with rectangular cross sections. These items collapsed well but did present problems when mounted in the cover. In the collapsed form they approximated flat plates and a rectangular box-like cover had to be provided. The excess material along the side edges of the foam could be folded back in accordion pleats. However, at the end of the pieces, where a block of foam butted against a second

piece, the opportunity of forming an accordion pleat did not exist. At these points, the excess fabric had to be gathered together and tucked down into the space between the blocks. There was no good method of securing the material so that it did not produce bulges. These bulges were particularly noticeable at the point in front where the upper block of foam, mounted on the chest, butted against the foam sections going over the shoulder, and at the rear where the shoulder piece adjoined the back piece. The substitution of foam pieces with circular or semi-circular cross sections and compartmentation with the breaks between foam sections coming at places other than where there is a sharp change in direction of the foam (e.g. the shoulder area) would be helpful. Adjoining blocks of foam on relatively flat areas, such as the chest, do not have this problem.

- An unsolved problem is one of mounting the collapsed blocks of foam in the carrier so that they do not shift around when worn and yet have sufficient freedom to expand when the flotation gear is actuated.

- Experience with the first four units showed that it would be very desirable to fabricate the carrier with the gas distribution system built into it. This arrangement would be much more satisfactory than having it as an add-on to an existing carrier. Such an improvement would eliminate the loose tubing in the present models and reduce the danger of hose kinking during assembly. Such an approach would also be helpful in positioning the blocks.

- The method of side closure and securing the entire assembly to the man needs improvement. The prototype models built during this program had their closure at the sides with Velcro straps pulled through D rings attached to the front of the carrier. Final closure was by adhering the Velcro to itself at the rear of the carrier. This rear fastening would make donning of the equipment by one man difficult.

D. Instantly Generated Polystyrene Foam Flotation System

Instantly generated polystyrene foam was the second foam system which was carried through the three phases of this program. It is a very rapid (practically instantaneous) way of forming a closed cell rigid polystyrene foam.

(1) Concept of Instantaneous Foam Formation

This flotation system is based on the use of rigid foam generated from polymers dissolved in liquefied gases. The liquefied gas (kept under pressure in a closed container), acts as the solvent for the polymer. As long as the solution is kept under pressure (the vapor pressure of the liquefied gas at the prevailing temperatures) no foaming results.

When the pressure container is opened to the atmosphere and the polymer solution is propelled from the container, foaming results. The foam forms because the solvent exists momentarily as a superheated liquid which flashes to vapor as soon as the pressure is reduced to atmospheric. As the liquid boils, it forms numerous bubbles in the polymer. The use of nucleation agents in the polymer solution causes a large number of small bubbles to form. The entire process of liquid boiling, foam formation, and stabilization by solvent loss happens in a fraction of a second. This method of making plastic foam had its beginning in the synthesis of polymers from their gaseous monomers some years ago. In the course of this work it was often observed that the newly formed polymer dissolved in the liquefied monomer under high pressure (20-25,000 psi). The dissolved polymer often produced foams when the pressure in the reactor was let down by venting unreacted monomer to the atmosphere.

The instant polystyrene foam system had been previously extensively evaluated. As a result of this work, composition and process conditions were thoroughly investigated and the properties of the rigid foam were optimized. The pressure necessary to produce high quality foam was reduced to 60 psi as a result of this work. Tests were conducted on the best instant polystyrene foam to determine its compressive strength, tensile strength, and flexural strength. The formulation for these test foams is given below:

Amt	Component
157.5 g	Lustrex HH-101 Polystyrene
6 g	Triton X-200
2.5 g	Glass microballoons
12 g	Genetron 21 (dichlorofluoromethane)
69 g	Dimethylether

These foam products were comparable in strength and buoyancy to commercial Styrofoam as well as commercial rigid polyurethane foam at the 2 pcf (0.032 g/cc) density level.

(2) Design of Flotation Gear Using Instantly Generated Polystyrene Foam

To support a 250-lb man wearing full aircrewman uniform and protective armor, it is necessary to provide approximately 0.75 cu ft of low density flotation material such as polystyrene. Figure 17 is a schematic diagram of the proposed system for the generation and distribution of the above quantity of the polystyrene foam. The equipment consists basically of a pressure container, explosively actuated valve, automatic water sensing and actuating mechanism, electrical power supply, and foam distribution and container system.

The system necessary for the generation of instant polystyrene foam is considerably more complex than that needed for performed flexible foam. Such items of the design of a valve suitable to handle the viscous polystyrene solution and the position sensitivity of the entire system had to be worked out.

(a) Conceptual Development (Phase 1)

The heart of the instant polystyrene foam flotation system is the pressure cylinder which holds the polymer solution and the valve which closes the cylinder. It was planned initially to use a cylindrical vessel, capable of resisting at least 100 psig, to hold the polystyrene and solvent/pneumatogen. It was expected that this cylinder could be manufactured from 3 in. diameter stainless steel or aluminum tubing having 0.012-in. thick walls. The original concept provided for the bottom of the pressure cylinder to be connected through a large diameter "U" shaped tube to a normally closed explosive-actuated valve.

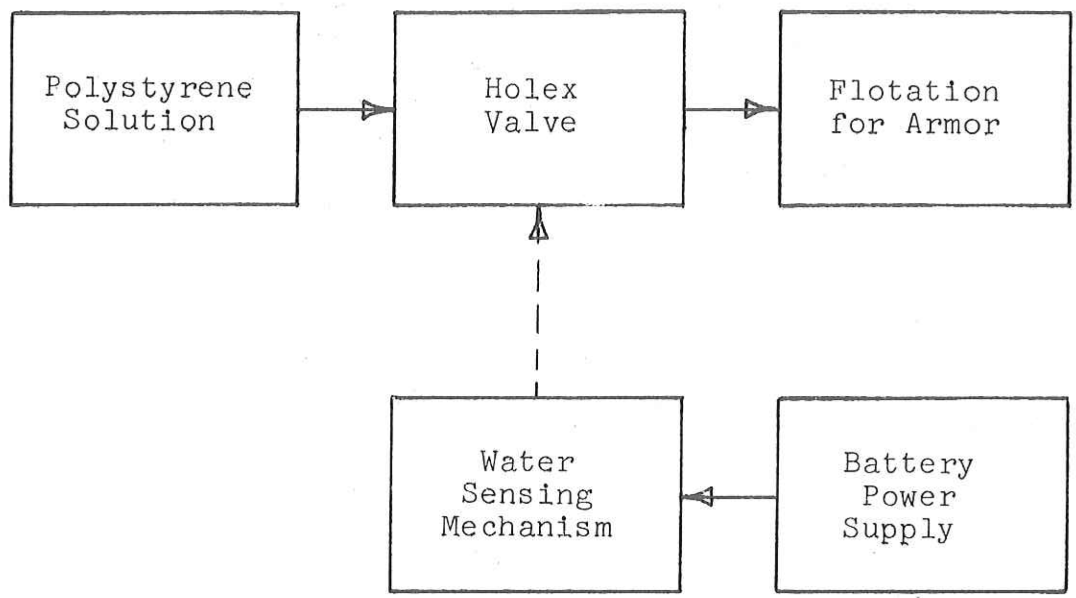


Figure 17. Simplified Schematic Diagram for the Polystyrene Foam Dispensing System

The configuration of the exit hole and the supply tube connecting the pressure cylinder and the explosively actuated valve is extremely important. It has been determined that the quality of the polystyrene foam depends upon its rapid exit from the container. Thus, if the container or the exit hole has some restrictions, the polystyrene foam will form at a slower rate, resulting in a poor expansion factor. Therefore, it is necessary to maintain as large a diameter as possible through the "U" tube and valve. Figure 18 represents the solution cylinder.

It is proposed to utilize explosively actuated valves for the release of polystyrene foam solution. These valves are commercially available and represent adequate design for the present state-of-the-art. They are actuated by a one-ampere current through 1.0-ohm resistance firing circuit.

It was initially proposed to locate the foam container close to the waist of the man with the outlet of the explosively actuated valve directed upward to facilitate the flow of polystyrene foam. The outlet of the valve would be connected to a flotation ring similar to the one described for the precompressed foam.

It was believed that the proposed polystyrene foam generation system could meet the requirement for the total weight to be less than 4.0 lb. However, the target bulk of 48 cu in. probably could not be achieved with this design.

An alternate concept was proposed that would be completely position insensitive. This is a pressure container with a rolling diaphragm separating the pressurized liquid chemical solution and a compressed gas section. Upon actuation of the valve, the gas would expand the rolling diaphragm and drive the solution out of the container. This alternate polystyrene foam system is illustrated in Figure 19.

(b) <u>Design of System (Phase 2)</u>

During the second phase of this program a complete design of a flotation jacket using instant polystyrene was carried out. This design was based on using the system shown on page 53. The design included the preparation of detail drawings to permit manufacture of all the component parts of this system. The equipment necessary for the operation of this system consisted of a pressure container, explosively-actuated valve, automatic water sensing and actuating mechanism,

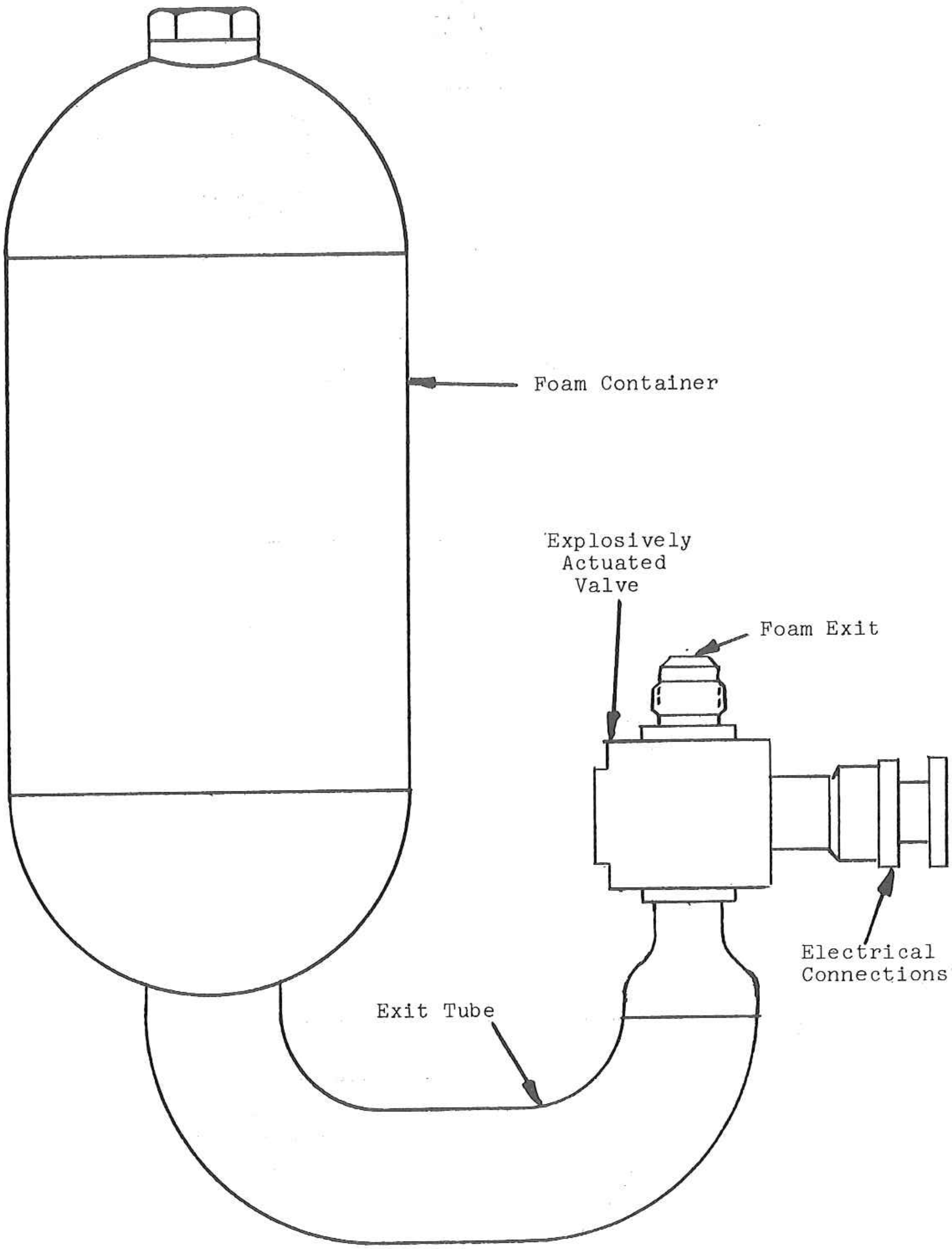


Figure 18. Simplified Layout of Polystyrene Foam System

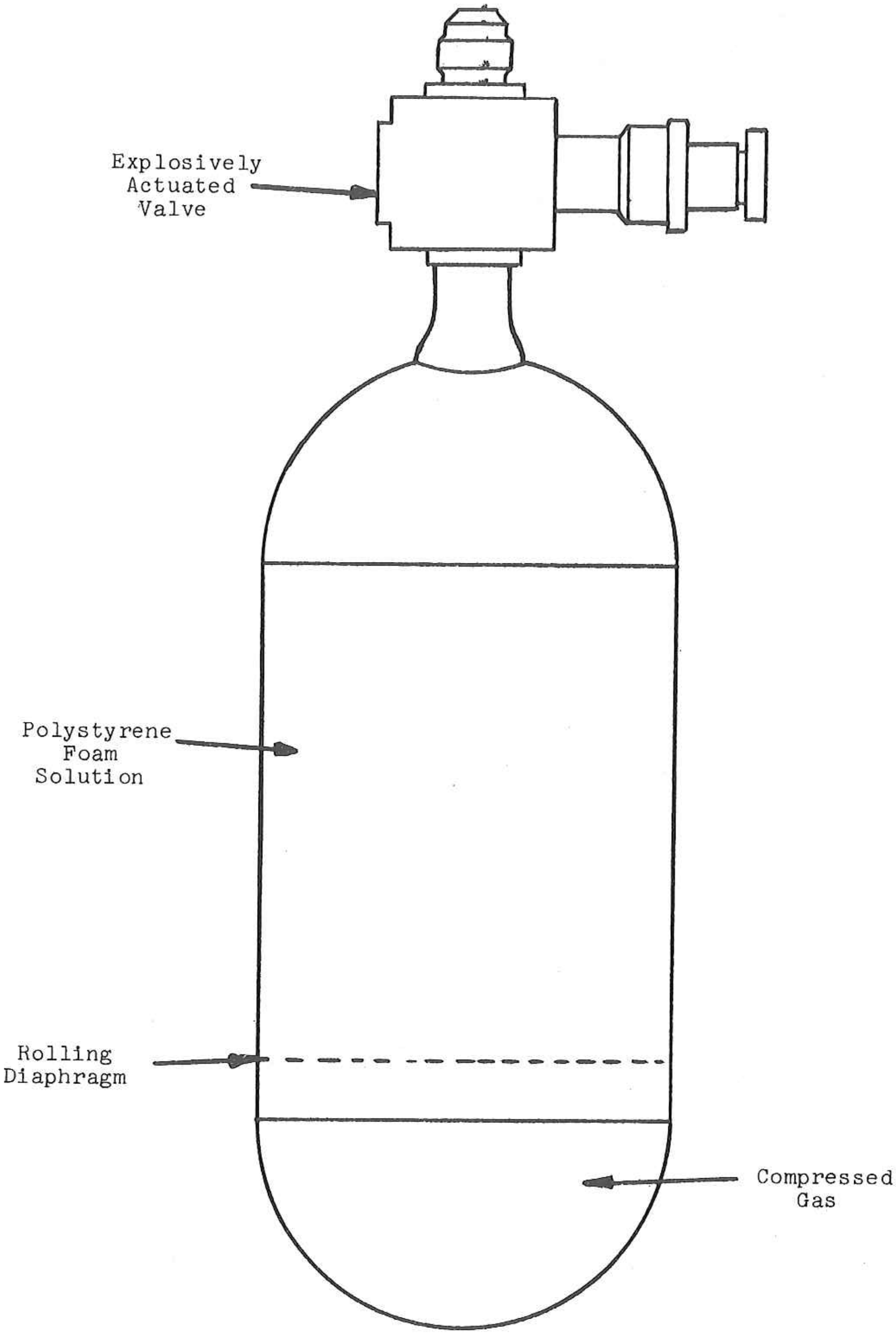


Figure 19. Rolling Diaphragm Type Polystyrene Foam System

and foam carrier assembly. The general view of the proposed polystyrene foam system as worn by a man as well as an outline of the carrier assembly is illustrated in Figures 20 and 21, respectively.

It is proposed to utilize two polystyrene foam containers located on each side of the carrier assembly. Each foam container (Figure 22) is approximately 30 cu in. in volume and consists of a main body, elastomeric rolling diaphragm, and an explosively-actuated valve. The foam container is placed in the vertical position with the exit valve uppermost in the carrier assembly. This was necessary because polystyrene foam has difficulty in flowing around corners as would be the case when the outlet is directed downward. However, poor foam is usually generated when the foam container is opened with the outlet in the upper position, as the gases necessary for the proper expansion of the foam collect in the upper portion of the chamber and escape prematurely when the valve is opened. To avoid this, it is proposed to include an elastomeric rolling diaphragm in the polystyrene foam container. The polystyrene foam solution is located above the diaphragm, and a lower container below the diaphragm is pressurized with a suitable gas. Upon activation of the valve, the pneumatic pressure behind the rolling diaphragm moves the elastomeric diaphragm and expels all of the polystyrene foam solution from the container. Short term material compatibility studies for the diaphragm were conducted. The best material for this application appeared to be ethylene propylene copolymer (Bellofram No. 140). We selected Bellofram Corporation to manufacture both the polystyrene solution container and its diaphragm. It was expected that the body of the container would be manufactured by techniques similar to the manufacture of aerosol cans and the diaphragm would be an integral part of the unit which would be roll-selaed into the main body. A diaphragm which would be suitable for only one operational cycle was proposed. It is possible that further work would show feasibility of a reusable rolling diaphragm.

A number of manufacturers were canvassed for the appropriate quick release valve for the polystyrene containers. To obtain adequate polystyrene foam expansion it is necessary to have a valve with at least a 0.625-in. diameter unobstructed opening. Most of the commercially available valves with this size opening are comparable to the size of the polystyrene container. This, of course, would be unacceptable from the human factor consideration. The most compact valve found is manufactured by the Conax Corporation. A similar but larger valve is illustrated in Figure 23.

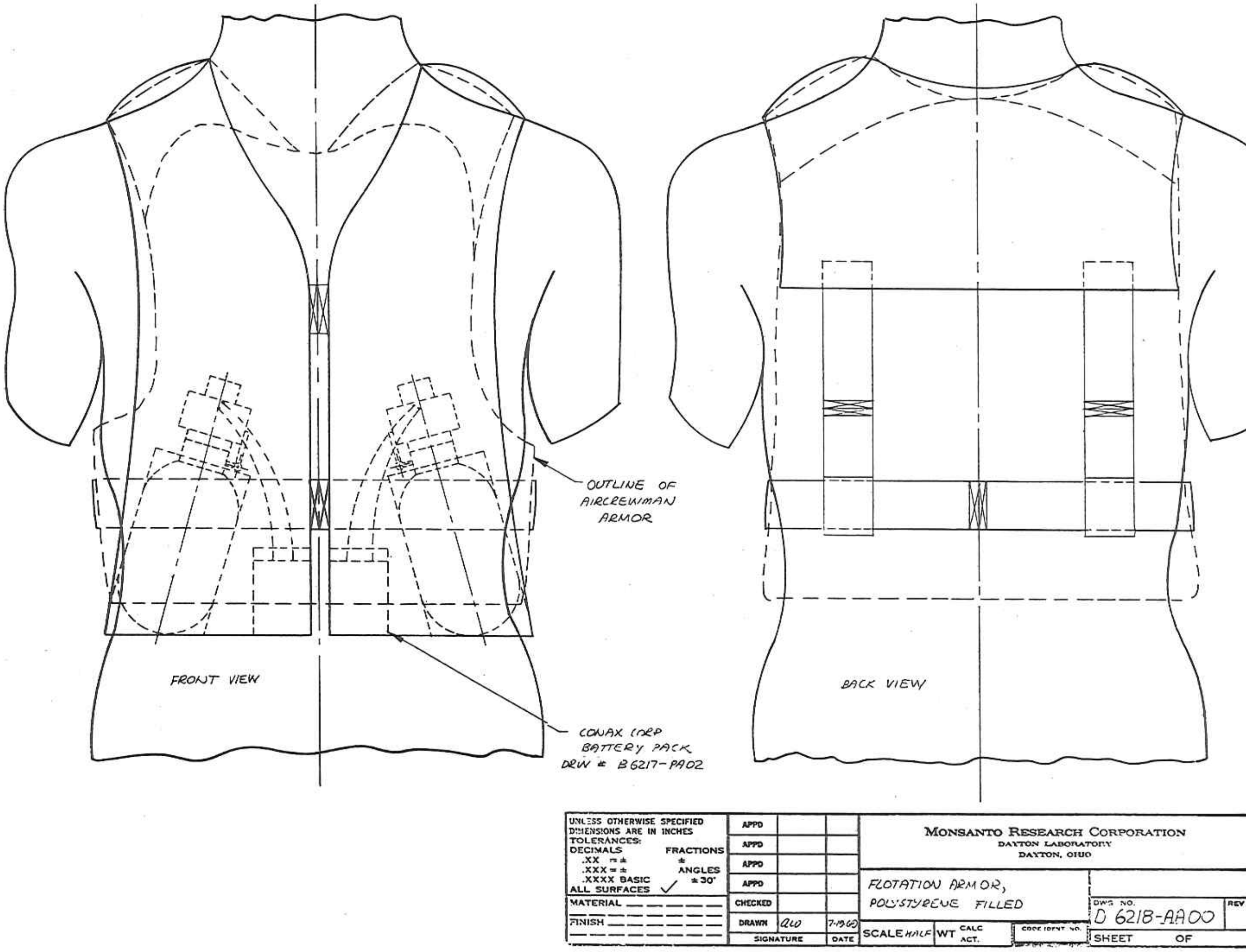


Figure 20. Polystyrene Filled Armor Flotation System

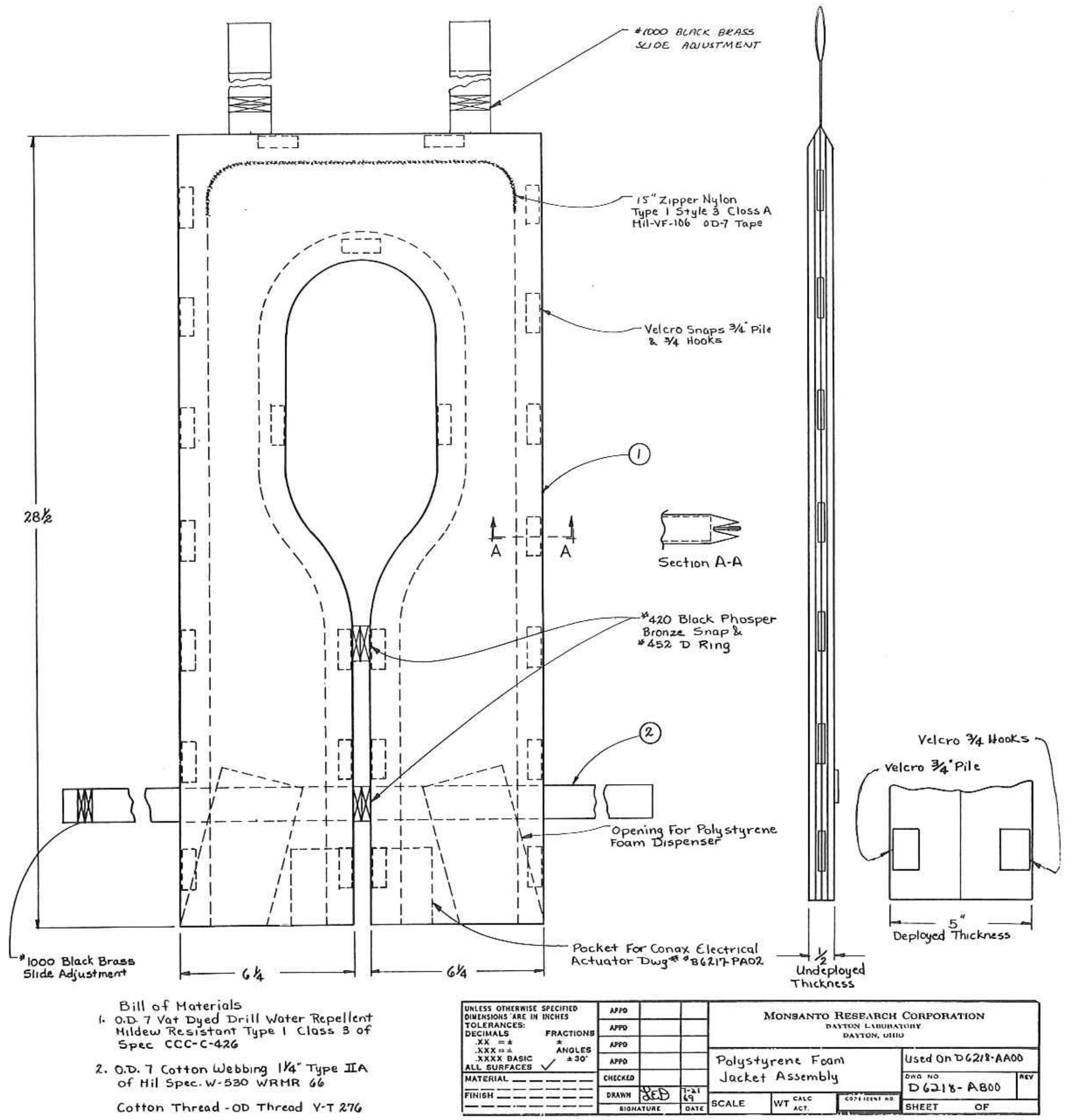


Figure 21. Polystyrene Foam Jacket Assembly

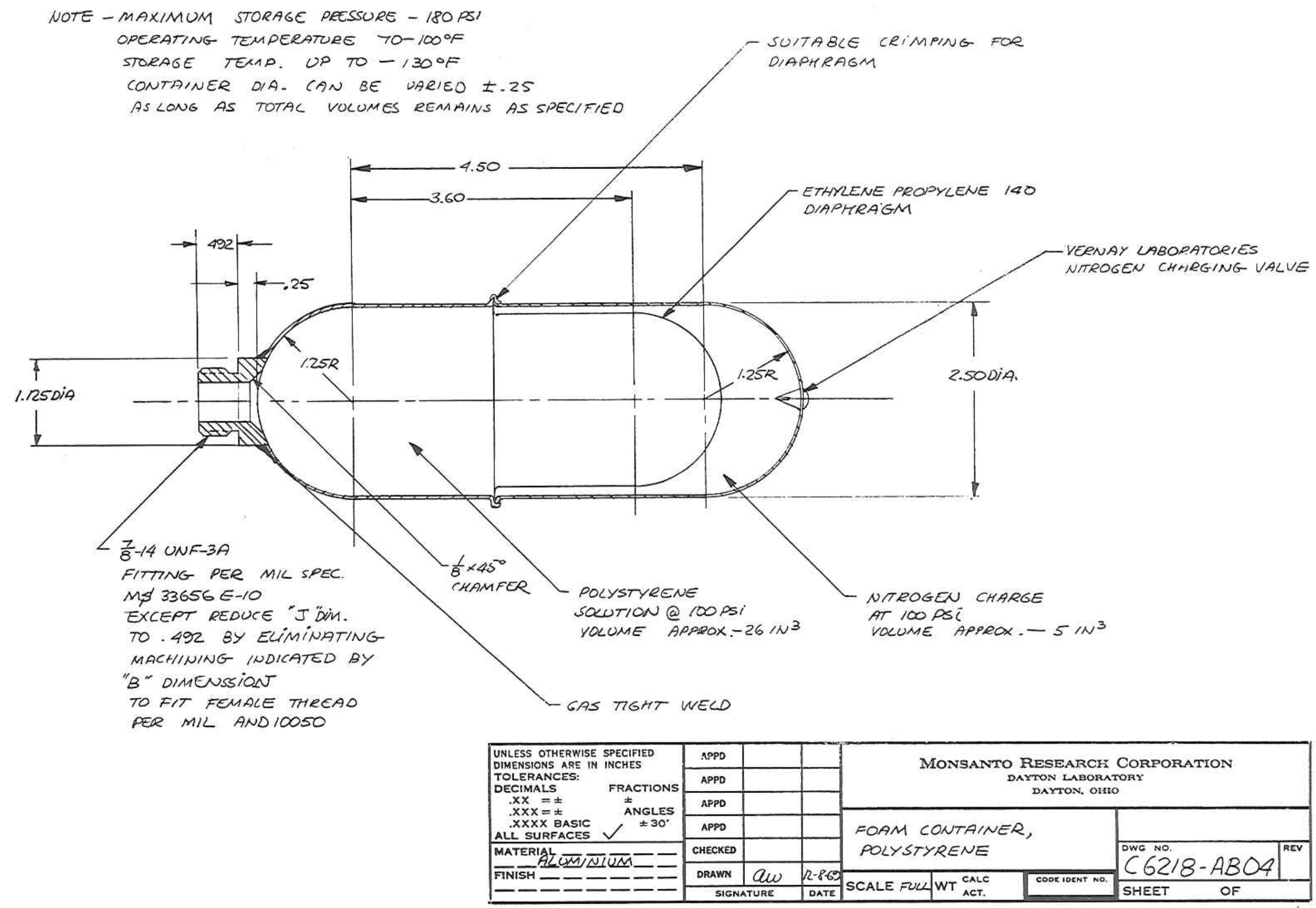
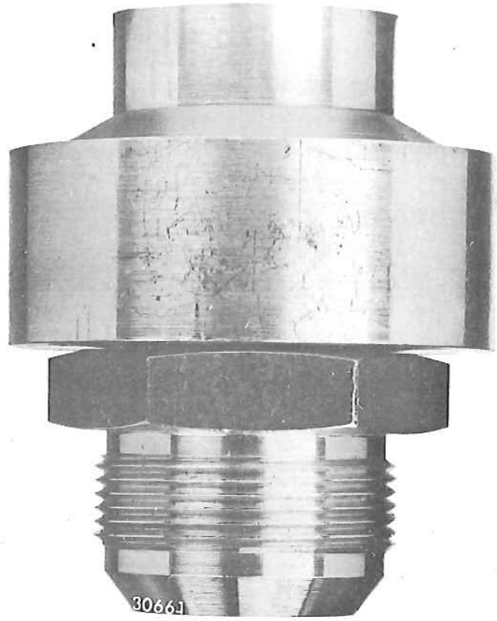
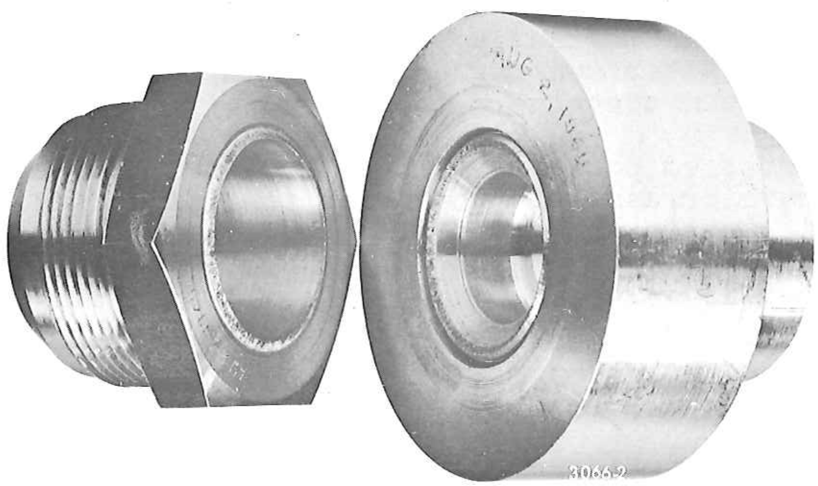


Figure 22. Container Assembly for Polystyrene Foam Dispenser



Before Activation



After Activation

Figure 23. Conax Corporation Explosively Actuated "Dump" Valve

The proposed nonsparking Conax Corporation valve is also exhibited on a drawing (Figure 24). This valve has the necessary 0.625-in. diameter straight-through opening. The valve is also explosively-actuated. Upon command from the sensing unit, the pyrotechnic cartridge is fired. This propels a shock wave through the valve body. The shock wave shears the valve at the separation line, and the upper portion of the valve separates from the body allowing the polystyrene foam solution to escape. One disadvantage in this design is that the sheared portion of the valve will travel with the foam. Thus, if not restricted, it might impinge upon the wearer. If the velocity is high enough, this might cause some injury. To prevent this, it was proposed to incorporate an assembly on the valve body which would prevent the head of the valve from traveling with the leading part of the foam. This was to incorporate either a hinge or a chain attached between the head of the valve and the foam container. The device was to limit the maximum travel of the sheared portion of the valve, but would allow the foam to escape and form the flotation system. The valve is actuated by a water sensing and activating mechanism. The water sensing and activating circuit is essentially the same as the one proposed for the activation of precompressed foam.

Essentially, the foam carrier assembly (D 6218-AB00) would have the same design features as the carrier for the precompressed foam system except that the vinyl bag assembly will not be necessary and appropriate pockets will be provided for the water sensing and actuating devices and the polystyrene foam containers.

The proposed polystyrene foam system consisted of a separate carrier assembly worn over the individual. Upon contact with water, the sensing circuits fire two pyrotechnic cartridges in the "dump" valves. The valves open and the foam is released into the carrier assembly, expanding the jacket as the foam progressed from both sides of an individual toward the head area. The expanded foam is closed-cell, thus presenting no problems with water pickup.

(c) Fabrication of System (Phase 3)

The second phase designs were not accepted because they required a separate jacket or garment to be worn over the armor. A flotation system which was an integral part of the armor/armor carrier is considered to be more desirable and the system had to be redesigned to meet the requirement. Because of time limitations much of the second phase design program had to be superimposed on the third-phase fabrication program.

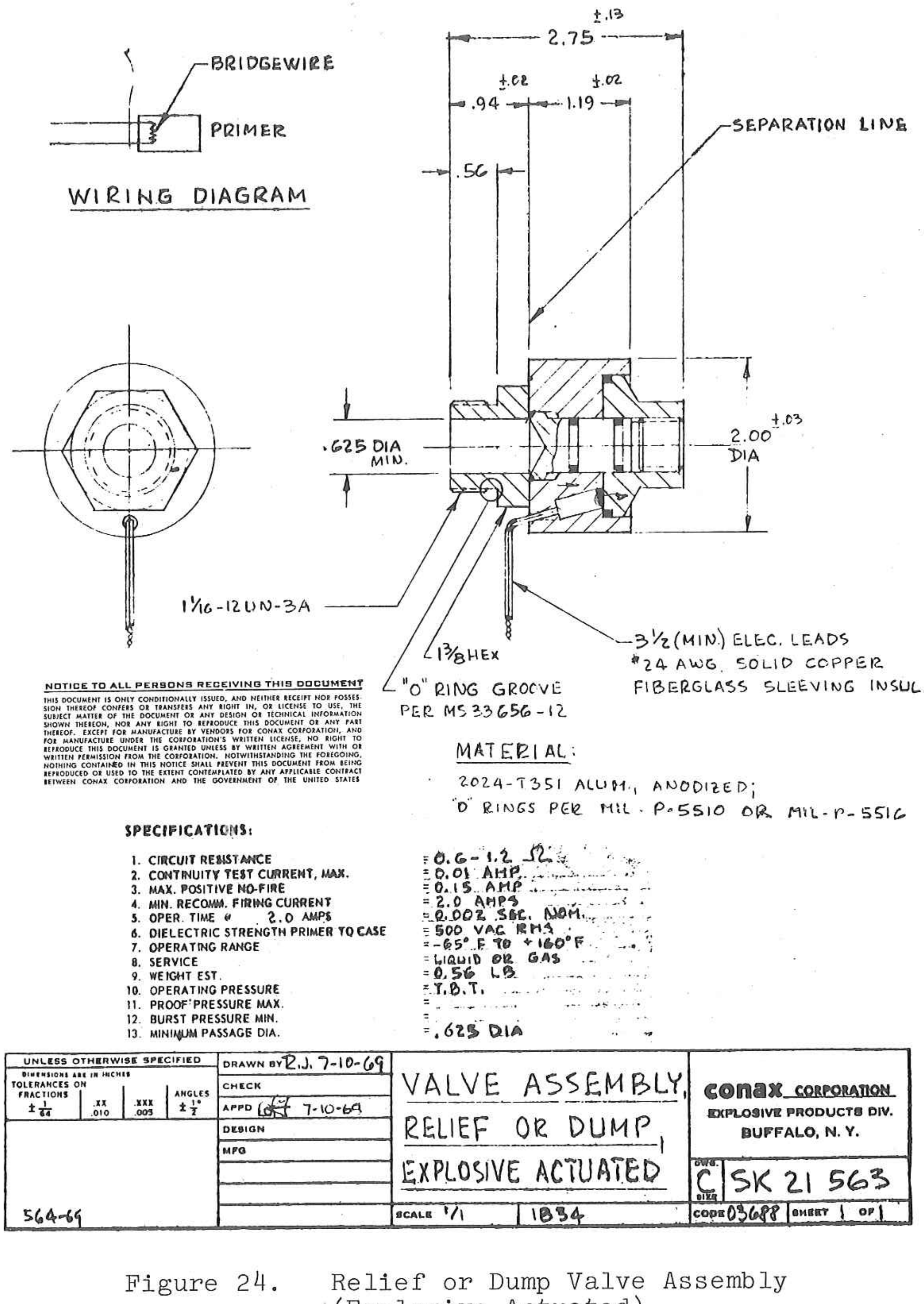


Figure 24. Relief or Dump Valve Assembly (Explosive Actuated)

In the final design, a cloth cover which serves to cover the foam and confine it within the flotation jacket was attached to the armor carrier. The cloth cover contains a plastic sleeve within which the foam expands. The lower ends of the plastic sleeve are fastened to the pressure bottles, which are carried in pockets on the front of the carrier. The valve ends of the bottles project upward into the cloth cover of the flotation device. Two bottles are provided for each jacket. Each bottle contains an electrically actuated explosive dump valve. Actuation is by a water-sensitive battery pack, one for each bottle.

The cloth components for this system, other than the government furnished armor carrier, were made to specifications. Three units were built during this phase of the work. The first had the bottles rather low down on an apron-like appendage hanging below the lower edge of the armor carrier. The second two were built with the holders for the cylinder, plus the front foam pocket moved higher up. Two individual pockets were also provided for the water-sensitive actuators.

An examination of the carrier reveals that the bottles are mounted rather near the center-line of the armor and they are low enough that they would probably constitute a problem to a seated man as they would interfere with his upper legs in the seated position.

Instant polystyrene foam requires a smooth, straight-line flow out of the bottle and into the jacket. Any abrupt change in direction of the foam, or restriction of it as it leaves the bottle results in decreased amounts of foam and generally poor performance. Because of this, straight-line flow out of the bottles and into the jacket are mandatory. These considerations dictate that the position of the bottles be low down on the carrier and directed along a line that carries the foam up and over the shoulders.

Alternative positioning may be possible if the idea of a foam collar is abandoned. Perhaps one cylinder could supply foam to a flotation package on the front of the armor and one to the rear of the armor. However, even with such a change, the problem of positioning the chemical bottle remains a difficult one.

The carriers have too much Velcro to take care of folding and securing excess material. The amount of Velcro used prevents the cloth cover from opening fully when the system is actuated. The problem is not so severe with the polystyrene foam as it was with precompressed foam as the inflation procedure is much more forceful.

The use of less Velcro, or one with less tenacity, may be helpful. The manner of securing the armor and its carrier to the wearer with closure at the rear is also objectionable as it makes it difficult for one man to don the equipment unaided.

The polystyrene foam system for this approach consists of two identical sub-systems. Each, in turn, consists of a polystyrene foam container with an automatic dump valve (Figure 25) and a water-sensing and actuating system. The sequence of operation is as follows: Upon contact with water, the sensing and actuating circuit closes the battery circuit. A current surge from the battery fires the pyrotechnic dump valve. The polystyrene foam solution is then released from the container. Complete ejection of the polystyrene foam solution is assured by nitrogen pressure behind an elastomer diaphragm which aids in expelling of the foam solution. A manual override is provided to actuate the dump valve if this should be necessary or desirable.

The polystyrene foam container is shown in Figure 25. It is essentially a cylindrical bottle with two chambers separated by a Buna N elastomeric diaphragm. This material was found to be impervious to the components of the polystyrene foam solution. This separation diaphragm was necessary in order to achieve uniform ejection of the polystyrene foam regardless of the orientation of the exit nozzle of the container. During loading of the container the 294 gms of polystyrene foam solution is forced into the top section of the container. This is performed while the container is cooled in the dry ice bath.

Upon loading, the explosive dump valve is attached to the system, thus effectively sealing the polystyrene foam solution in the container. The bottom chamber of the container is then charged with nitrogen at 120 psig. This nitrogen pressure exerts a force on the rolling diaphragm and facilitates proper ejection of the polystyrene foam solution from the container regardless of its orientation. The explosive SK 2106 dump valve for the polystyrene foam system is shown in Figure 26. It is actuated by an electrical current flow from the battery to the explosive charge in the valve. The explosion of the charge produces shock waves which in turn shears the valve disk thus releasing the foam solution. Figure 27 shows the pressure bottle plus valve and disk which is sheared from it. During the actuation cycle, the explosive charge inside the valve does not come in contact with the contents of the container. Thus, it is safe to utilize this valve

Figure 25. Cylinder for Polystyrene Foam Solution Equipped with Automatic Dump Valve

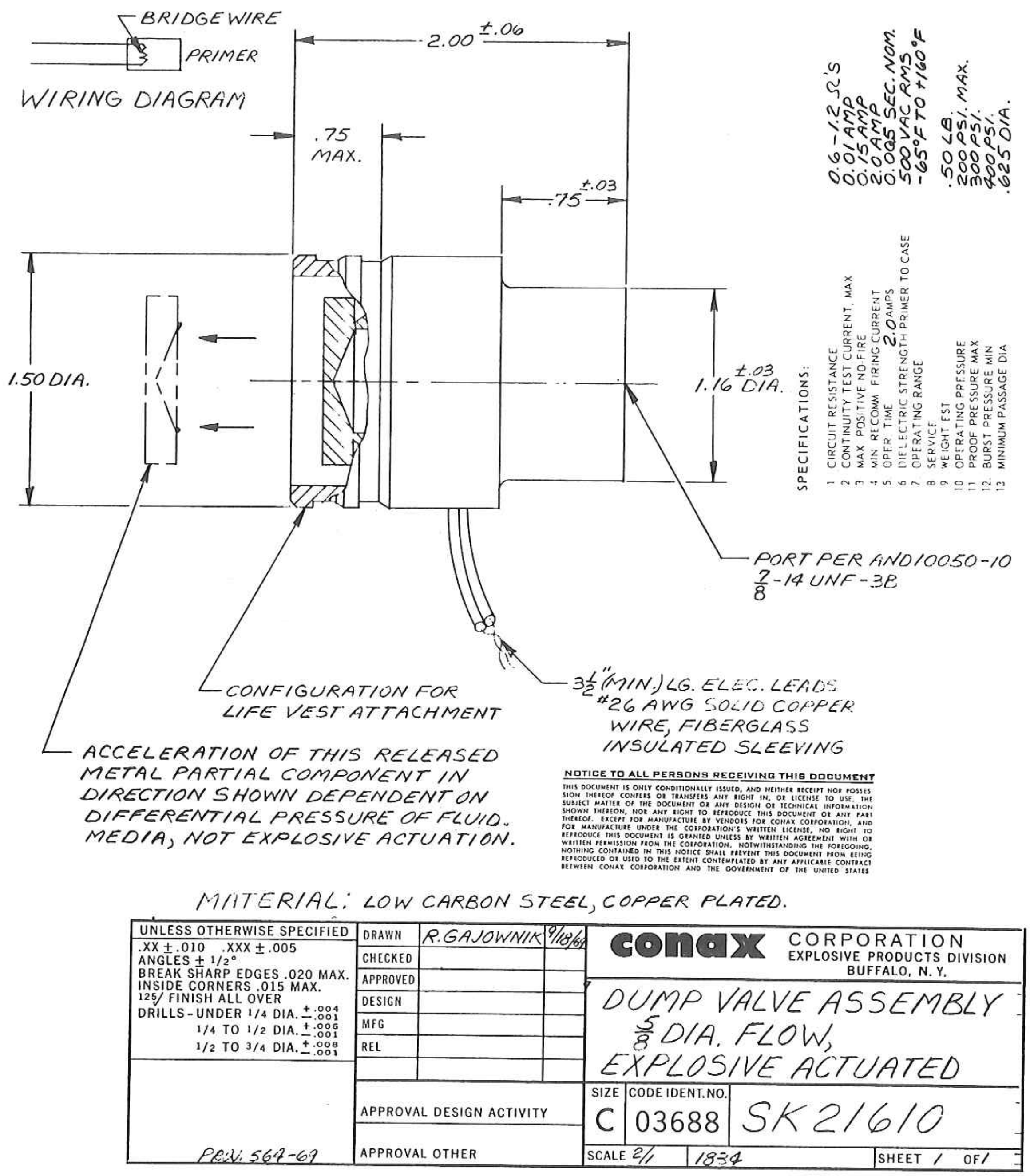


Figure 26. Dump Valve Assembly, 5/8 inch Diameter Flow. Explosively Actuated

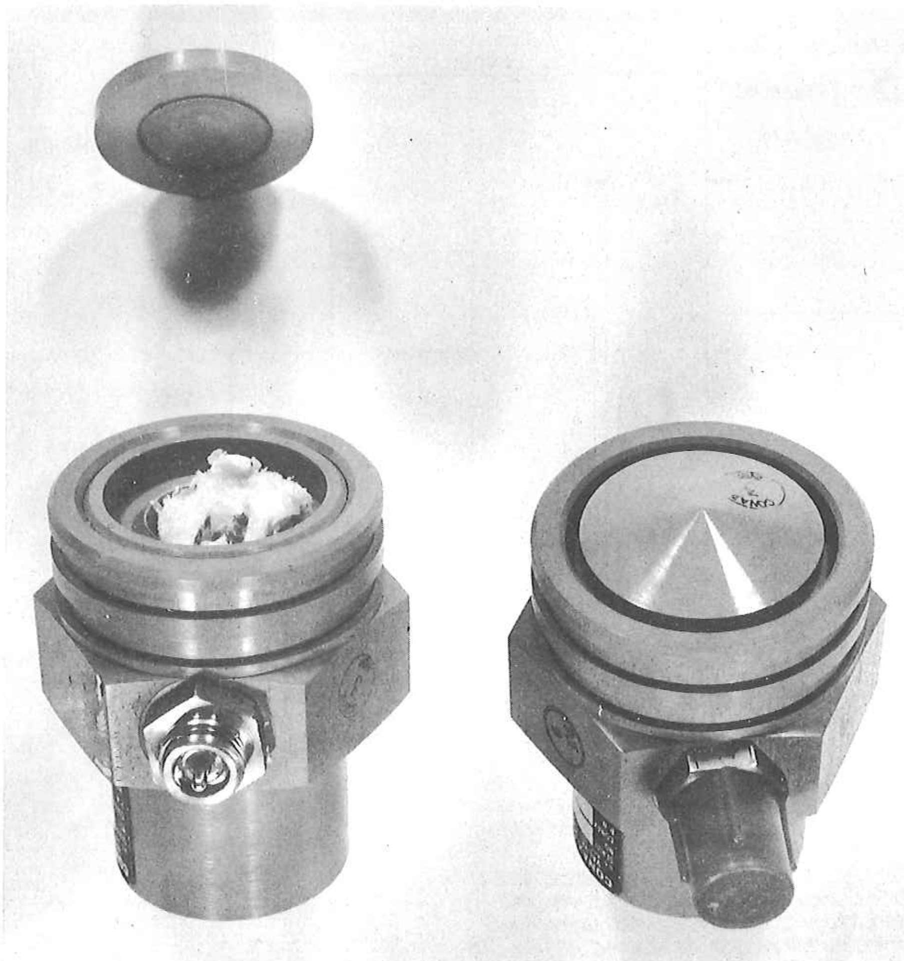


Figure 27. Explosively Actuated Dump Valve, Before and After Use, Showing Sheared Closure Disc

with flammable mixtures as is the case with the polystyrene foam solution during its initial expansion stages. The water-actuating and sensing system is essentially the same design as that of the "Aid Pak" except that the piercing mechanism for the CO_2 cartridges has been removed. Upon contact with water it provides an electrical signal necessary to actuate the explosive valve. A manual override actuating mechanism is also provided.

(3) Testing Program

The polystyrene foam solution was well developed at the start of the program. As a consequence, no experimental foam development program was needed. Because of this all testing was carried out after the final designs were made. The test program was severely limited because of the cost of the experimental explosively-actuated valves. Because of this, the bulk of the testing was done using polystyrene foam containers fitted with 3/8-inch diameter or larger manual ball valve. This was done to determine how the system worked and still preserve the limited number of the automatic dump valves available. During these tests it was confirmed that the quality of ejected foam depended greatly upon the design characteristics of an exhaust nozzle. Any obstructions in the exhaust passage impede the flow of foam material, and results in foams with poor expansion factors. Good quality foam is achieved only if a smooth, large diameter path is provided. To achieve good quality foam with the manual ball valve it is necessary to minimize all obstructions in the flow passage. Also, the manual valve had to open cleanly and rapidly. Any hesitancy in opening the valve resulted in a poor foam. Using a manual valve polystyrene could be made to fill foam approximately 70 percent of the flotation collar. The foam did not fill the areas behind the shoulders.

The next series of tests were carried out in the water. The polystyrene foam container with an automatic water sensor dump valve was attached to the armor flotation system. The whole assembly was then physically thrown into water. The dump valve was immediately actuated and the polystyrene foam was immediately ejected into the carrier. As in the case of the manual actuation the foam quality was good but it did not fill the volume around the shoulders.

The last tests with the polystyrene foam system were performed with a man wearing the jacket. The armor carrier was worn by a fully clothed man (Figure 28). Upon immersion in

Figure 28. Man Wearing Armor and Instant Polystyrene System

water both polystyrene foam cylinders were immediately actuated and the foam was expelled into the flotation carrier. Immediate flotation was achieved. However, the area around the back of the neck was not filled with foam. Thus, although flotation was more than adequate it was improperly distributed. This was due to the inability of this foam to flow freely around sharp obstacles and/or curves. Immediately upon actuation of the polystyrene containers, the test subject smelled a strong odor of dimethyl ether vapor. The odor persisted for several seconds. No ill effects were observed.

(4) <u>Advantages of Instant Polystyrene Foam System</u>

High quality rigid foams are produced from polystyrene dissolved in either dimethyl ether or mixtures of dimethyl ether and a fluorocarbon. This foam-generating system is capable of producing strong buoyant foam, instantly. The foam is lightweight and dimensionally stable immediately after being formed. The foam generator is also lightweight and simple to operate, either automatically or manually. The foam system does not depend on a chemical reaction. Therefore, adverse use conditions are relatively unimportant in their effect on foam quality.

A final advantage of the instant foam system is that it has a long storage stability of up to one year at temperatures as high as 130°F. There are no components in the formulation that deteriorate at temperatures below 250°F.

(5) <u>Disadvantages of Instant Polystyrene Foam System</u>

A pressure cylinder is required to contain this foam system at about 60 psi, and this would be vulnerable to damage by gunfire. If the cylinder were punctured, the foam would release immediately. Also, present formulations contain moderate amounts of flammable solvent (dimethyl ether), which adds to the hazards associated with premature foam release. Some progress has been made in replacing the dimethyl ether solvent with nonflammable fluorocarbon solvents, but a suitable replacement for all of it has not yet been found.

It should be emphasized that danger of fire during deployment of the instant polystyrene armor flotation system is negligible. In this case, the foam and vapors are contained within the flotation vest, and the foam is released while the armor is at least partially submerged in water. The polystyrene foam itself, once generated, is no more flammable than other common plastic foams. The instant polystyrene foam

system is sensitive to temperature. As the temperature decreases so does the internal pressure of the liquefied gas. The system works well down to about 30°F. Below this temperature the expansion ratio decreases rapidly. At low temperatures, the foam is denser and it ejects with very little force. If low temperature operation is contemplated, then over-pressurizing the formulation with carbon dioxide may be necessary.

Finally, the most severe obstacle to successful deployment of armor flotation by instant polystyrene foam is that the rigid foam does not flow around turns.

(6) Summary of Polystyrene System

In summary, the instant polystyrene foam system's advantages are:

- Polystyrene foam forms instantaneously.
- High quality foams at the 1.5-2.5 lb/cu ft densities can be produced.
- Polystyrene foam exhibits good flotation properties.
- Only approximately 1.35 lb of chemical solution is necessary to produce 0.75 cu ft of 1.8 pcf foam.
- Equipment necessary for producing foam is relatively simple and lightweight.
- Chemical formulation of the polystyrene foam is simple.

The system's disadvantages are:

- Polystyrene foam system is somewhat position sensitive. This may not be a serious problem if the proper design of the pressure cylinder is carried out.
- The configuration of the exit hole from the polystyrene pressure container is critical.
- Polystyrene foam flows poorly around corners and obstructions.
- To date, all formulations have contained at least some dimethyl ether (a flammable solvent).
- This foam system is sensitive to temperature. It works well down to 30°F.
- A pressure cylinder is required. This cylinder would be subject to damage by fragments or gunfire; if the cylinder were punctured the foam would form immediately.

- The polystyrene pressure container is bulky and would interfere to some degree with the movement of the aircrewman.

E. Two Component Polyurethane Foam Flotation System

The above was the third concept which was carried through the three phases of the program. It is the concept which was least developed during the program but appears as having the greatest potential for development in future work. It can never be as compact as the preformed flexible foam but does offer the possibility of forming a closed-cell foam which can be made to flow around bends.

(1) Rapid-Reacting Urethanes

A rapid-reacting urethane system is based on a multi-component foam formulation and can produce flexible, semi-rigid, or rigid buoyant foams depending on formulation. This foaming process differs from the instant polystyrene in that the urethane polymer is synthesized while the foam is expanding. The physical properties of the polymer are developed by the time the foam is completely expanded.

The urethane foam system was well established. Very little work was done under the armor flotation project to further develop the urethane foam formulations. Instead, the work was directed mainly toward designing and fabricating the storage chamber, quick-opening valves, and mixing assembly to adapt urethane foam for armor flotation.

A typical formulation for rapid reacting flexible urethane foam is shown below:

Component	Amt.
POLYOL SOLUTION	
Pluracol P-1010	382 g
Water	6 g
DABCO R-8020	4 g
Freon 11 (trichloromonofluoromethane)	8 g
Silicone DC-190	1 g
Genetron 115 (monochloropentafluoro-ethane	80 g

Component	Amt.
ISOCYANATE SOLUTION	
Mondur MR	200 g
Freon 11	8 g
CATALYST COMPONENT	
Nuocure 28 (stannous octoate)	6 g

This formula produces a flexible foam which has extremely small cells, is hydrophobic, and its density is about 3 pcf (0.048 g/cc).

Rigid low-density urethane foams have been successfully prepared by the same methods used to prepare the flexible foam described above. The rigid foam contains closed cells and therefore would provide an added measure of safety if the vest were badly damaged. Small cell flexible foam will take up water even after it has been treated with water repellent agents such as zinc stearate if it is subjected to rough handling or flexing and pumping action while completely submerged. There is some danger that a rigid foam, if its polymer has a high modulus, may be quite friable and could break up if handled roughly.

As a compromise between flexible and rigid foams small cell semirigid foams can be prepared by mixing a flexible and a rigid formulation to obtain the desired properties. The flexible formulation is the major constituent in the mixture since rigid foams only are produced where less than 70% of the flexible component is added. The 70/30 mixture produces a tough and relatively hard, semirigid foam of about 3 pcf density with open cells. Adding more than 70% of the flexible component to the mixture makes the foam product softer, and it remains open-celled.

Semirigid foams offer the possibility of reaching a compromise between rigid, closed-cell foams and flexible, open-celled ones.

(2) Design of Flotation Gear Using Polyurethane Foams

Polyurethane foams are produced by mixing two liquid reactants together. One reactant contains active hydrogens supplied from the hydroxyls present on polyethers or polyesters. The other reactant contains isocyanate groups. Along with these reactants a pneumatogen is added to produce

the gas needed for expanding the foams. Other necessary additions are surfactants to control cell structure and catalysts to control the foaming rate. In commercial foaming practice the two reactants are kept in separate tanks until use time. At that time the ingredients are brought to a mixing nozzle or head by pumps. The pumps plus metering valves insure that the right amounts of each reactant plus other ingredients reach the mixing nozzle or head. There, the several ingredients are intimately mixed and the mixture is then run into molds or onto a moving belt where foaming occurs as the two reactants react with each other.

The above process is very precise and requires rather elaborate and heavy equipment. In the quick-reaction urethane foam system for armor, all of these operations will be expected to occur without bulky equipment and to occur automatically once the system is actuated.

(a) <u>Conceptual Development (Phase 1)</u>

The first concept for this system visualized a fully automatic system that contained both reactants plus pneumatogen and other ingredients within a single outer shell. A simplified schematic diagram of equipment for the generation of the polyurethane foam is illustrated in Figure 29. Figure 30 illustrates the approximate layout of the polyol and isocyanate solution container and the mixing chamber. The equipment consists of solution container, explosively actuated pressure cartridge, three rupture disks placed at strategic locations, plastic polyol container, and an outlet duct. The upper portion of the container is filled completely with liquid isocyanate and liquid Freon or Genetron. Thus, the whole upper cavity is under 100 psig pressure. The center small cavity between the two rupture disks is filled with the catalyst at zero pressure. The lower plastic or aluminum container is attached to the bottom of the upper chamber and is filled with the polyol. The chamber immediately around the plastic container serves as a mixing chamber during the activation cycle.

The sequence of operation would be as follows: Upon command from the sensing mechanism, a pressure cartridge would be electrically activated. This pressure cartridge generates enough additional pressure above the 100 psig

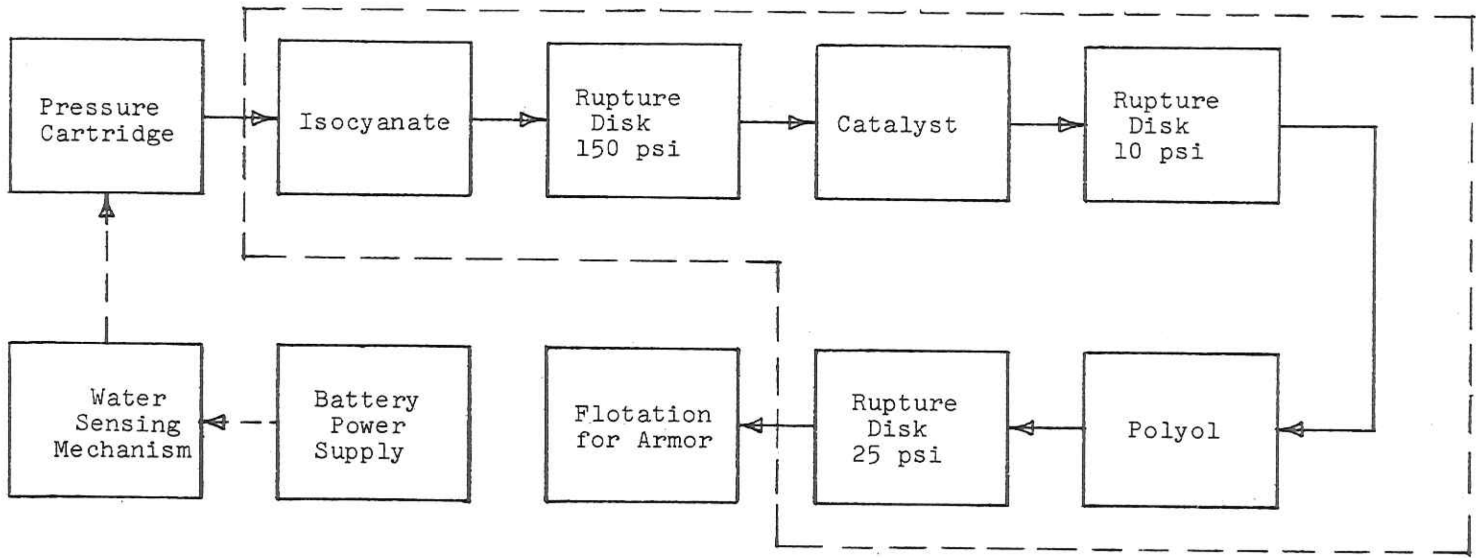


Figure 29. Simplified Schematic Diagram of the Polyurethane Foam Dispensing System

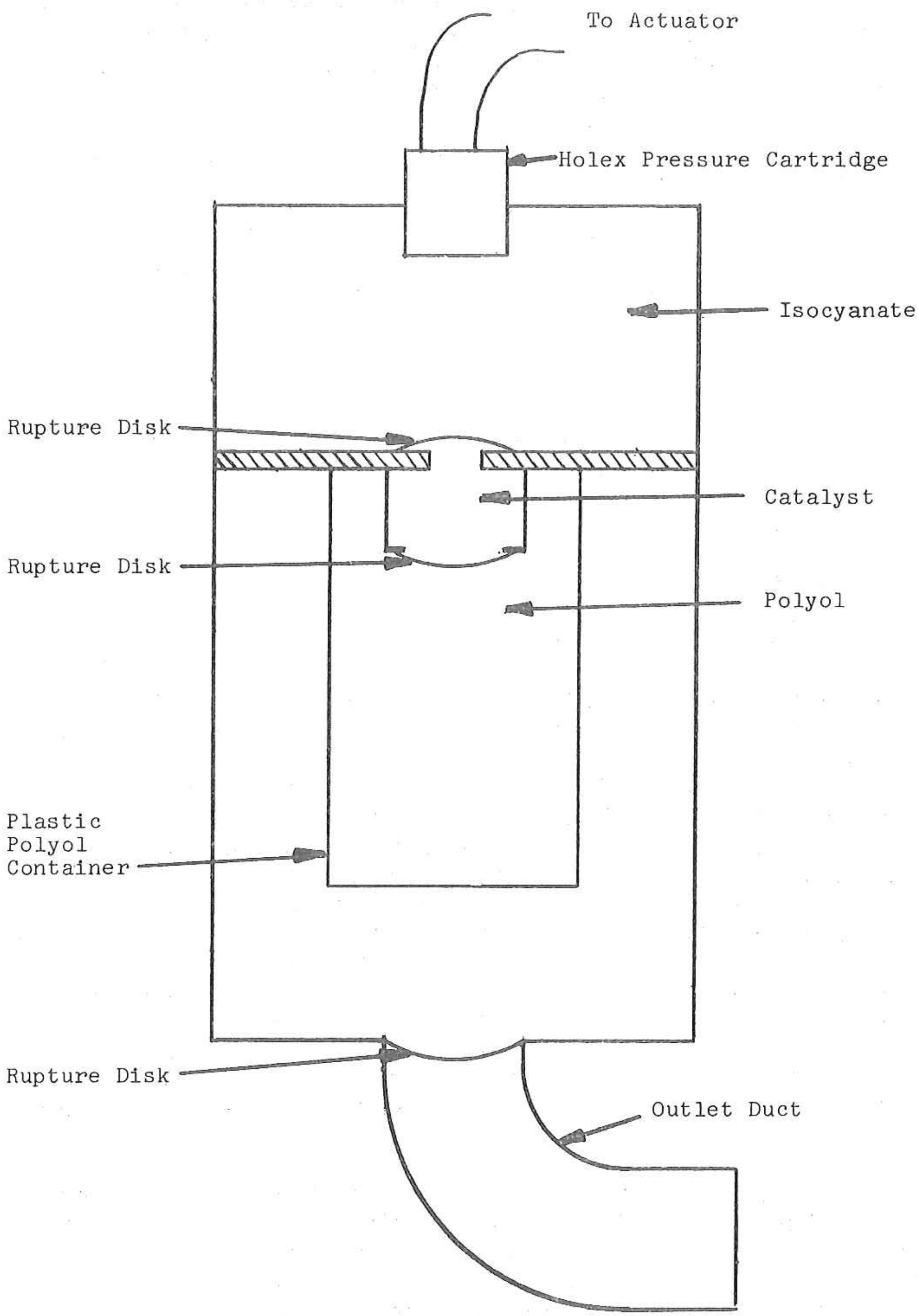


Figure 30. Simplified Layout of Urethane Foam System

already in the chamber to rupture the first rupture disk. The isocyanate solution would then be rapidly expelled into the catalyst chamber. The pressure would rupture the second rupture disk, and the whole solution would be propelled into the polyol plastic container. The plastic container ruptures readily under the pressure, and the three components of the urethane foam are rapidly mixed together in the lower chamber. The last rupture disk would be broken due to the additional pneumatic pressure as well as pressure due to the reaction of the chemicals. At this time the foam would be generated and expelled through the opening of the outlet duct into the flotation container.

The pressure cylinder proposed for this system is a rather complex unit with three separate chambers requiring careful design and adequate seal between the units. This seal is achieved through the properly designed rupture disks.

The pressure cartridges are commercially available and are activated by 1 ampere current. The automatic water sensing and firing circuit proposed for this design is discussed on pages 21 and 29.

A prototype unit of the urethane foam distribution system having essentially the same features discussed above was constructed and tested utilizing the proposed electrical circuit and cartridges. Tests performed with the upper chamber filled with water were successful. The upper rupture disk performed its desired function of not breaking at 100 psig and rupturing at approximately 150 psig. Tests with the isocyanate solution in the upper chamber, however, failed to rupture the first disk. This could be due to the fact that some gas pockets existed in the upper chamber or that the isocyanate solution absorbed the gaseous products of explosion at a very rapid rate. In any case, it is believed that this deficiency can be corrected either by eliminating gaseous voids or by selection of pressure cartridges having higher energy generating capabilities, or both.

It is proposed to locate the urethane foam container close to the waist of the man, with the container being essentially in the horizontal position and the outlet duct of the unit connected to the foam container similar to the one described for the precompressed foam.

It was believed that the proposed polyurethane foam distribution system can meet the target w ight requirement of not more than 4 pounds. However, the volume requirement of 48 cu in. was not attainable. It was believed that a minimum of 72 cu in. will be necessary to provide an adequate flotation system.

(b) Design of System (Phase 2)

For the polyurethane foam system, it was initially proposed to utilize the foam-generating and dispensing system shown in Figure 31. Two containers were proposed, one located on either side of a man wearing a foam carrier assembly which was essentially similar to the jacket assemblies proposed for the other systems, except that special provisions were made for the urethane foam dispenser and the actuating system (Figure 32).

The operating sequence of the urethane foam dispensing system is as follows: Upon command from the water sensing and actuating assembly, the pyrotechnic cartridges are fired. This should generate excessive pressure in the polyol container, resulting in breaking of the rupture disc. The polyol solution would then be expelled from the chamber to the catalyst container. Excessive pressure would rupture the second rupture disk and the two components would be expelled into the isocyanate container. A series of five rupture disks would be ruptured and the three (now partially mixed) components would be expelled into the mixing chamber where thorough mixing should take place. The last rupture disk would be broken by additional pneumatic pressure as well as by pressure due to the reaction of the chemicals. At this time, the foam would be generated and expelled through the opening of the c let duct into the flotation container.

Either the Holex Corporation's Series 6300 or Co ax Corporation (1621-081) pyrotechnic cartridge was sugg ted to provide the necessary over pressure in the polyol container to break the initial rupture disk. This cart idge would be actuated by the same water sensing and firing circuit described in the polystyrene section of this report.

The cloth carrier was essentially the same unit as was proposed for the polystyrene foam system except that special provisions were made for the storage of larger urethane foam containers.

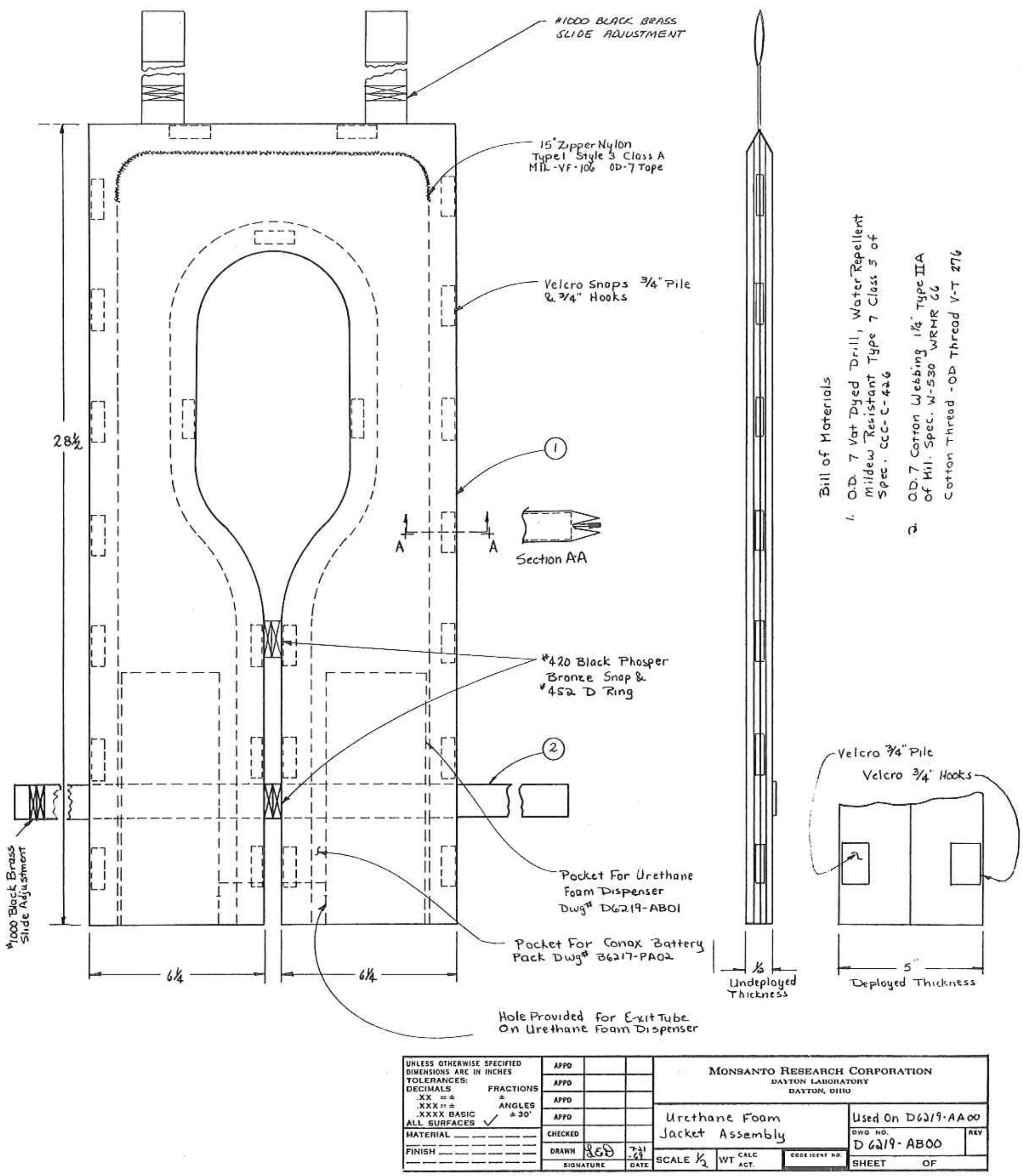
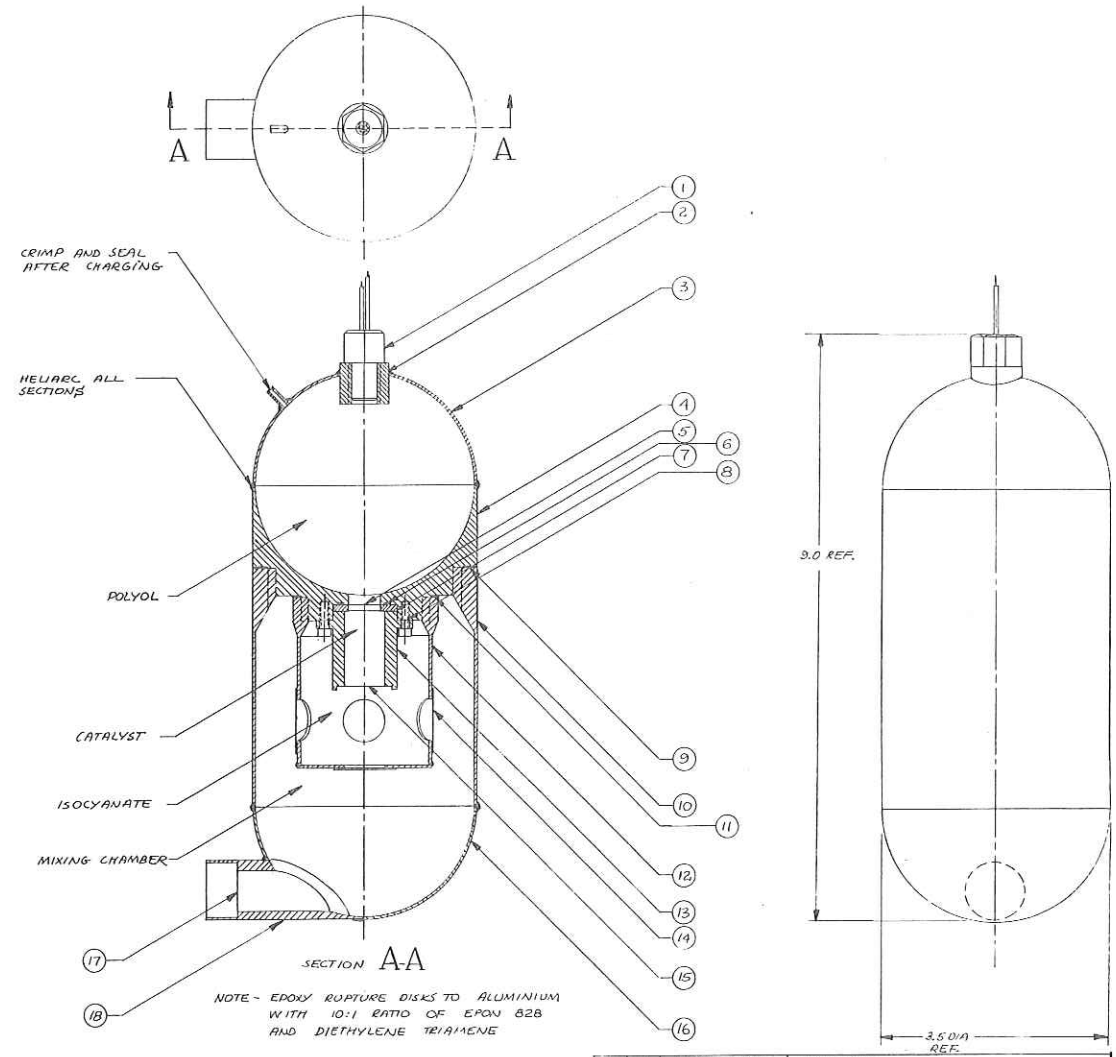


Figure 31. Urethane Foam Jacket Assembly



PC. #	* RE.	DRAWING NUMBER	DESCRIPTION
18	1	A6219-PB18	EXIT TUBE
17	1	A6219-PB17	ROTURE DISK, URETHANE FOAM
16	1	B6219-PB16	EXIT HEMISPHERE
15	1	A6219-PB15	RUPTURE DISK, CATAL
14	5	A6219-PB14	RUPTURE DISK, ISOCYANATE
13	1	A6219-PB13	CATALYST CONTAINER
12	1	A6219-PB12	ISOCYANATE CONTAINER
11	1	A6219-PB11	GASKET
10	1	B6219-PB10	MAIN BODY
9	1	A6219-PB09	GASKET, INNER
8	6	——	5-40 SOCKET HEAD CAP SCREWS, 3/8" LONG
7	1	A6219-PB07	BACKUP PLATE
6	1	——	#016 BUNA-N PRECISION "O" RING
5	1	A6219-PB05	RUPTURE DISK, POLYOL
4	1	B6219-PB04	LOWER HEMISPHERE
3	1	B6219-PB03	UPPER HEMISPHERE
2	1	A6219-PB02	FITTING ADAPTOR
1	1	1621-081	CONAX PRIMER CHAMBER ASSEMBLY

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES:
DECIMALS .XX = ± .XXX = ± .XXXX BASIC
FRACTIONS ± ANGLES ± 30'
ALL SURFACES ✓
MATERIAL
FINISH

APPD / APPD / APPD / APPD / CHECKED / DRAWN aw 7-8-69 / SIGNATURE / DATE

MONSANTO RESEARCH CORPORATION
DAYTON LABORATORY
DAYTON, OHIO

URETHANE FOAM DISPENSER
USED ON D629 AB00
DWG NO. D6219-AB01 REV
SCALE FULL WT CALC 1.60 ACT. CODE IDENT NO. SHEET OF

Figure 32. Polyurethane Foam Dispenser

The estimated weight and volume was substantially higher than was originally estimated in the Phase 1 effort. Original weight and volume requirements were arrived at on the assumption that 1.5 pcf urethane foam density could be achieved. While this is theoretically possible and is being achieved in large-scale production, subsequent work on small batch type mixing setups indicated that 3.0 pcf foam density would be a more realistic figure. This, of course, necessitated an increase in the weight and volume requirements for the system.

(c) Fabrication of System (Phase 3)

The Phase 2 designs were not accepted, necessitating a redesign during the part of the program which should have been devoted solely to fabrication.

One of the designs proposed in Phase 2, is a three-compartment foam generator. One compartment contains the polyol, the intermediate small compartment, the catalyst system, and the third compartment the isocyanate. The polyol compartment is under pressure. Each compartment is separated from the others by a rupture disk. The disk would be strong enough to resist the ambient pressures in the system. At use time, the pressurized polyol compartment is over-pressurized by a pyrotechnic gas-generating cartridge. The over pressure would cause the rupture disks to break in sequence resulting in successive mixing of polyol with catalyst and finally with the isocyanate. After this sequence was complete, the final seal would rupture and the foam mix would exit to the flotation gear.

Large-scale, heavily built, models of this system showed that foams of good quality could be made very rapidly. However, a consideration of the problems associated with miniaturizing this complex piece of equipment and making it dependable, compact, and sufficiently light in weight indicated that such a development was beyond the scope of this program.

A simpler system was substituted. This consisted of a commercially available foam generating system of two pressurized aerosol type cans, one containing polyol plus propellant (Freon) and the other isocyanate plus propellant. At use time the valves on the cans were actuated and the respective chemicals flowed through tubes to a mixing head and then to the flotation jacket.

This substitution offered the possibility of using an already developed foam generating system that was relatively light in weight. It does have the disadvantage, however, of being somewhat bulky and requires two containers. It is position sensitive as currently developed but could be made position insensitive by packaging the chemicals in cans containing bellows or diaphragms with pressure on the back side of the diaphragm. The cans are somewhat slow to empty in their present state (30-35 seconds) and the foam becomes rigid in an additional 30 seconds. This is too slow for flotation use; however, the supply cans could be made to empty more rapidly by providing valves with larger through-ways and larger diameter delivery tubes. The foam could be made to cure faster by formula adjustment.

Despite these deficiencies, this appeared to be an attractive system and one capable of refinement to produce an acceptable means of generating foam for flotation.

(d) Polyurethane System

The polyurethane system is a commercial urethane foam dispenser assembly consisting of two containers, one containing pressurized isocyanate and the other the polyol solution. Each of the containers have simple dispenser type valves usually found in shaving cream dispensers. The outlet of each container is directed through a small diameter tube into a plastic mixing chamber. Upon the simultaneous actuation of valves of both containers, each liquid solution is forcibly propelled into a small plastic chamber where violent mixing takes place. The resultant mixture was expelled from the mixing chamber and reacted chemically, producing high quality urethane foam. The commercial polyurethane foam system was modified to demonstrate its feasibility for the flotation armor system. Each container is fitted with a simple spring-loaded valve-actuating mechanism. The mechanism is actuated by pulling on a lanyard which released two pins restraining the actuating springs.

(e) Carrier Plus Cover

The Government-furnished carriers were modified to provide a cover for the foam system, pockets for the two-component urethane cans, and passageways between the carrier and the cover for the tubes bringing the chemicals to the mixing nozzle mounted inside the cloth cover. Sufficient excess

cloth material was provided in the cover to provide for expansion of the foam. The excess material was folded into an accordion pleat around the perimeter of the armor and secured with Velcro(R) tape.

The modifications of the carrier were made and three jackets were built. The first one had the foam component cans mounted too low on the carrier which would interfere with a man when seated. The two later models had the pockets for the cans moved to the side and up. This placed them at the side at waist level. Figure 33 shows this carrier.

The biggest deficiency of this carrier plus flotation system only showed up in tests where the carrier contained armor and the entire assembly was worn by a mannequin or a man. Under these conditions, when the belt at the waist was drawn up tight, the foam generation system functioned poorly. If the carrier did not contain armor or the assemblage was not drawn up tight at the waist, the foam system functioned well. After a considerable amount of experimentation, it was discovered that under normal use conditions (armor in place and securely fastened to the wearer) the liquid delivery tubes were binding between the cover and the armor plus carrier. When this occurred the hose was restrained in its ability to move and the valve on the can would not move far enough to open fully. This resulted in irregular and uneven time of delivery from the cans and a poor foam resulted. In extreme cases where one can emptied in 30 seconds and the other in 2 minutes or more, no foam was obtained.

This deficiency only became apparent during final testing on the finished assembly. Improvement could probably be obtained by:

- Redesign of the carrier and foam cover to prevent binding.
- Use of fixed tubes with short bellows type connections to chemical supply cylinders.
- Redesign of the valve to do away with need for lateral movement, and provide for larger diameter openings in valve to give quicker emptying.

As in other systems, too much and too strong a Velcro(R) fastening was used to insure ready opening of the foam cover. Also, the method of securing the carrier plus foam system at the rear was objectionable. Side closure should be provided for.

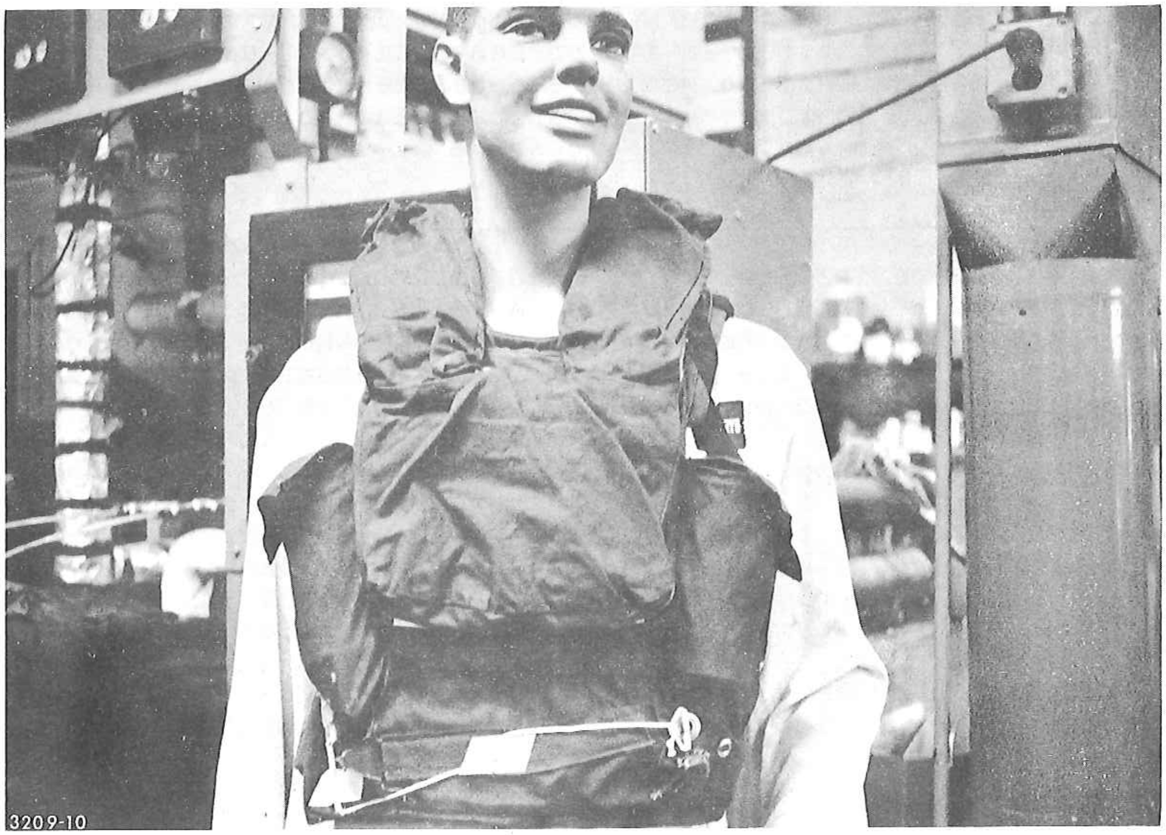


Figure 33. Armor Carrier Plus Polyurethane Flotation System

Improvement in foam ingredient containers would also be very helpful. Containers that fit the contour of the armor and well to the side would help to do away with the bulkiness of the system in its present state of development. Such a refinement would be feasible with the polyurethane system as the components are reasonably fluid, flow well, and are not under excessive pressures.

(3) Test Program (Polyurethane System)

Tests were initially performed with the polyurethane foam system attached to the armor carrier and installed on a mannequin. Initial tests indicated that the valve was not actuating fully all the time. The valve actuating mechanism was then modified to provide for greater valve deflection and freer movement. Subsequent tests resulted in a good quality foam and approximately 90-95% fill of the flotation carrier. Unfilled flotation spaces were in back of the carrier. The next sequence of tests was with the armor carrier and armor immersed in the small water tank. Good quality foam was produced within approximately 20 seconds and the urethane foam filled approximately 90% of the flotation carrier. A subsequent test was with the urethane foam system and the armor assembly worn by a man. The subject was immersed in the water and manually actuated the flotation system.

The system did not function because one of the valves did not actuate properly. Thus, only one component of the urethane system was released and consequently no foam was generated. The actuating system was again modified to provide for freer movement of the dispenser valve and the discharge line. The system was again successfully tested several times. The urethane foam system was then tested on a man once more (Figure 34). A man wearing the polyurethane flotation system entered the water tank and manually actuated the valving mechanism. On two consecutive tests the system did not function. It was determined that malfunctioning was due to excessive snagging of the discharge valve and nozzle by the armor carrier. This occurred only when the carrier was worn by a man. All but one of the previous tests were performed in a small water tank without a man. In this case the movement of the valves and lines was not unduly restricted and the system functioned properly. However, when the flotation armor was worn by a man all fasteners had to be secured, resulting in a frictional force which impeded free movement of the valve as well as the discharge line. Thus, the valves

Figure 34. Man Wearing Armor Plus Polyurethane Flotation System

could not open properly resulting in an inoperative system. Subsequently, the system was again successfully demonstrated in a small water tank. It is believed that this frictional restriction can be readily corrected by providing an unobstructed space for movement of the valve and the discharge line even when the carrier is worn by a man. Redesign of the valve would also be helpful.

(4) Advantages of Polyurethane System

The principal advantages of the rapid reacting urethane are:

- The urethane foam froth as ejected by the mixer flows readily and can be shaped to produce any desired configuration.
- If a formulation which gives a closed-cell product is used, the problem of water pick-up by the foam is eliminated.

(5) Disadvantages

The principal objections to the system are:

- It requires a complicated chemical formulation that is temperature sensitive and so requires catalyst adjustment for the extremes of the operating range.
- It requires complicated foam storage cylinders, metering valves, liquid distribution system, and mixing nozzle. All of these components have to function well by themselves under adverse conditions. The wearer cannot make adjustments to improve any of the several operations that are occurring during foaming.

F. Overall Evaluation of Systems

Of the three concepts evaluated in actual mock-ups, the precompressed foam system is by far the most advanced. With minor improvements and refinements this system could be applied to existing armor and its carrier. It needs a number of refinements to move it from the mock-up to the prototype stage. They are:

- Change geometry of foam blocks to give a more nearly circular cross-section.
- Improve geometry of the back of the collar to make it less bulky.
- Prepare foam blocks as separate moldings with an integral skin.
- Provide for a better means of folding and securing excess material.
- Provide a gas distribution system which is integral with the carrier to reduce the danger of kinking tubes.
- Improve the closure at the right shoulder.
- Shorten the length over the shoulders.
- Move the foam behind the armor if at all feasible.

Many of these items could be provided for when the present carrier is redesigned or replaced with a new carrier.

The instantly generated polystyrene system is a very rapid reacting flotation device. It is fully automatic, a feature which is no longer desired, and gives a good amount of flotation material.

This system suffers from two major defects:

- The foam will not flow around corners. It is fully formed as it exits from the supply cylinder and would like to continue in the direction of propagation. If it meets an obstruction or a change in direction, the foam piles up on itself. Once it starts this, the forward push at the obstruction is lost and the foam does not move forward. Efforts to overcome this deficiency have not been effective.
- The second deficiency is that a flammable solvent is used in preparing the polystyrene solution. Other nonflammable liquefied gases have been investigated but none of them have served as a replacement for the dimethyl ether in use at the present time.

The difficulty with failure of the foam stream to follow the contour of the armor (flow around curves) could be avoided by providing a foam chamber at the front and rear of the armor

carrier; each one could be filled from a separate container. This would avoid the difficulty of trying to make the foam flow over the shoulder and around the back of the neck.

The problem of the flammable solvent does not appear to be readily corrected at this time.

The two-component urethane foam system is the least advanced at this time. However, it does offer the promise of giving full automatic operation and an acceptable system with further work. It is inherently more complicated than either of the other two systems because it depends on metering two chemicals together in fairly accurate amounts, mixing them adequately, and forming a polymeric foam at the time of use. Because it depends on a chemical reaction, it would also be more temperature dependent than the other concepts. This concept would require a considerable amount of design work and experimentation to make it a practical flotation system.

G. <u>Other Systems Prepared for Use in Armor Flotation Systems</u>

The following alternate approaches would also be effective in providing the required flotation to body armor. They were proposed as conceptual approaches in the Phase 1 study but were not carried into Phases 2 and 3.

(1) <u>"Bubble-Pack" Material</u>

"Bubble-Pack" is a commercial packaging material consisting of two sheets of plastic film heat sealed to form a single sheet with pockets of trapped air spaced at regular intervals. This material can be made in the form of a vest to be worn either over or under the present body armor. Since each air pocket is separate, damage to any one would not affect the others.

This approach represents the least weight since there is no storage container or actuating device. Response time for the system is zero. The disadvantages of this system are that it is bulky and warm to wear. It is also fragile in the sense that it would be highly susceptible to damage by snagging. These disadvantages might be lessened by perforating the plastic sheet between air pockets to permit air circulation through the vest, and by making the plastic film thicker, or by providing a light, snag-resistant fabric cover for the "Bubble-Pack".

(2) Open-Cell Foams Containing Closed-Cell Foam Beads

The flotation material used in this approach would be entirely new. It would consist of a sheet of open-cell commercial flexible foam containing polystyrene (expanded) beads inside each open cell. As in the approach above, a vest could be made from this material that would have a high degree of flexibility and buoyancy.

Two methods are recommended for making this new material. One involves foaming a conventional polyurethane formulation up through a bed of pre-expanded polystyrene beads. The other involves filling a large-cell commercial urethane foam (e.g. Scott Foam) with under-expanded polystyrene beads just large enough to fit loosely in each cell. The composite would then be heated carefully to expand each bead about 20% more and assure a tight fit overall.

In addition to the vest configuration this composite material could be used as slabs or patches fastened anywhere on the body armor. Its greatest advantage is that it combines the flexibility and breathability of an open-cell foam with the buoyancy and durability of a closed-cell rigid foam. Its principal disadvantage is that it is bulky because it must be worn in the fully deployed configuration.

(3) Hybrid Systems

Hybrid systems offer the best features of two or more individual foam flotation systems. For example, the pre-formed, stearate-treated foam in its vacuum bag could be placed around the back of the neck and along the upper edge of the front armor plate where it would afford chin protection and properly oriented buoyancy. Coupled with this system, the instant polystyrene foam system could provide the necessary flotation (i.e. two appropriately placed foam cylinders) over the chest area. At the same time the excess gas pressure from the polystyrene container could activate or deploy the compressed foam.

Another hybrid system of possible interest would be a combination of instant polystyrene foam deployed over the chest and rapid-reacting urethane foam deployed around the neck.

H. Water-Sensing and Valve or Pressure Cartridge Actuating Systems

The following approaches to automatic actuation of the flotation system were considered during the program.

- Use of cartridge-piercing mechanism used on a British Life Jacket. This system depends on the use of fibrous discs which expand rapidly on contact with water.
- Conax Aid-Pak(R) designed for use with current pneumatic life jacket.
- A water-sensing and firing circuit developed by Monsanto Research Corporation during the program.

The Conax Aid-Pak was selected as the actuating device for the demonstration models. The essential features of the Monsanto circuit (Figure 35) are described below:

- A safety lockout switch provides an absolute assurance circuit; the circuit will not fire while in storage.
- A sensing unit is used to trigger the gate of SCR 1 through bias circuit R2, R1, R3.
- R4 and D1 latches SCR are closed once the trigger to the gate has been applied. Once fired, the SCR continues to conduct through the squib cartridge and can only be reset by opening S1.
- Circuit voltage is supplied by V2 consisting of three 1.5 volt size D cells. Mallory Duracel or equivalent alkaline batteries are used.
- R5 and S2 provide a manual fire circuit by by-passing the sensing element to trip the gate to the SCR.
- Trigger potential to the SCR is set by the bias circuit in such a way that full immersion of the sensing element into conductive solution (i.e. water) will fire to SCR while high humidity will not cause the circuit to fire.

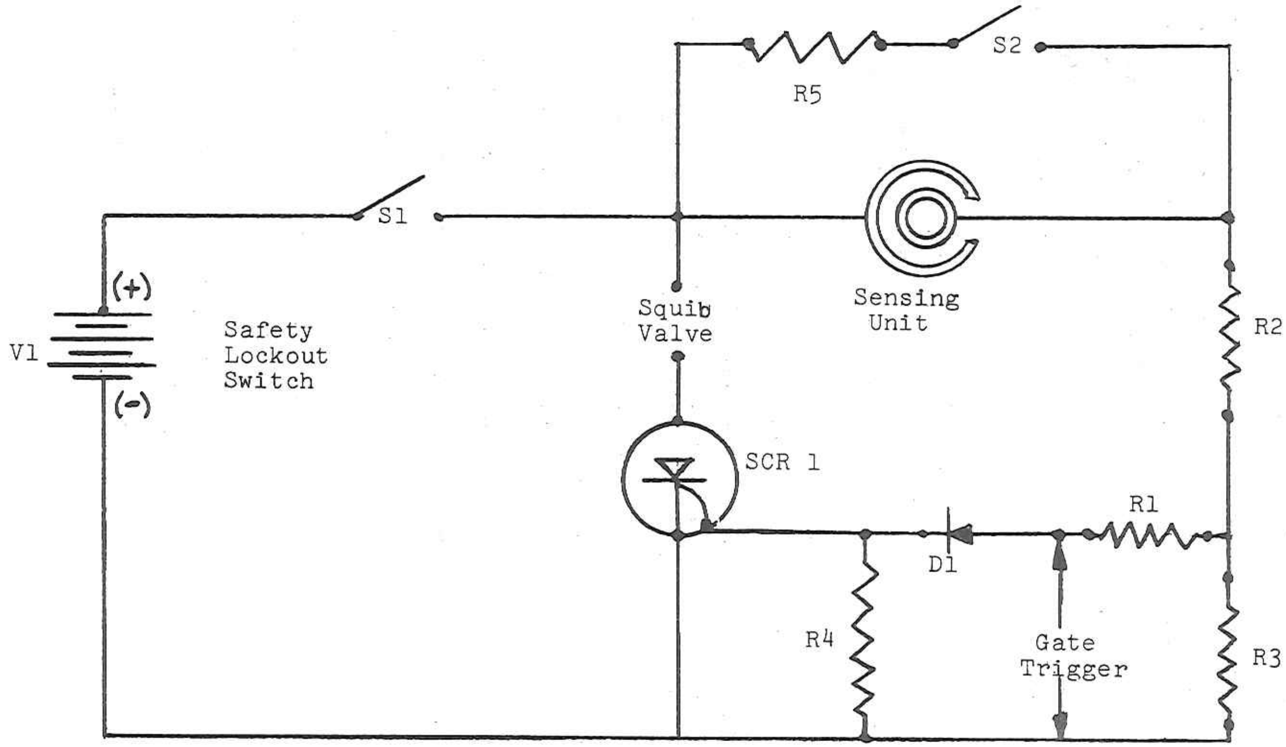


Figure 35. Water Sensing and Electrical Actuating Circuit

The circuit was constructed and tested successfully on several occasions under normal operating conditions utilizing tap water as an activating medium.

I. Gas Generation by Chemical Means

(1) General Considerations

It would be very desirable to be able to use the water in which the man plus his equipment is immersed to generate gas. It appeared feasible that the water could be used to cause two or more dry chemicals to react to produce gas instantaneously. This gas could be used to inflate the vacuum packaged precompressed foam discussed in Section C. Such reactions were investigated during the first phase of the program.

A search was made for chemical reactions capable of generating gas for inflating the collapsed foam. During this study, the following limitations were considered.

- The reacting chemicals should not be harmful to the person in contact with them.
- The required amount of these chemicals should be competitive with the total weight of the commercial small compressed CO_2 cylinders.
- The gas-generating reaction should start instantly when triggered.
- The reaction should start without heating.
- The generated gas should not be poisonous.
- The chemicals used should be inexpensive.
- The chemicals should not need to be stored under pressure.

Based on the above listed specifications, two approaches were considered.

- Instant CO_2 generation by the oxalic acid/potassium permanganate reaction.
- Instant CO_2 generation by the sodium bicarbonate/citric acid reaction.

Oxalic acid is readily oxidized by potassium permanganate according to the following reaction:

$$3 \begin{array}{c} COOH \\ | \\ COOH \end{array} + 2KMnO_4 \longrightarrow 6CO_2 + 2KOH + 2H_2O \qquad (1)$$

The reaction is exothermic. It is activated by water. Theoretically, 270 g of oxalic acid will react with 316 g of potassium permanganate to produce 264 g of CO_2 which will occupy 4.75 cu ft at standard conditions. For the production of 1 cu ft of CO_2, a total of 124 g of oxalic acid and potassium permanganate is required.

Sodium bicarbonate will react readily with citric acid in the following manner.

$$3NaHCO_3 + HO\text{-}\begin{array}{c} CH_2COOH \\ | \\ C\text{-}COOH \\ | \\ CH_2COOH \end{array} \longrightarrow 3CO_2 + HO\text{-}\begin{array}{c} CH_2COONa \\ | \\ C\text{-}COONa \\ | \\ CH_2COONa \end{array} + 3H_2O \qquad (2)$$

The reaction is endothermic and is started readily by water. According to the equation, 252 g of $NaHCO_3$ will react with 192 g of citric acid to produce 132 g of CO_2 that will occupy 2.4 cu ft at standard conditions. To produce 1 cu ft of CO_2, a total of 185 g of sodium bicarbonate and citric acid will be required.

The chemicals employed in the above two reactions are inexpensive. Higher yields of CO_2 can be obtained from the oxalic acid/potassium permanganate reaction. However, both of these chemicals could possibly be hazardous under certain conditions. Oxalic acid is poisonous and potassium permanganate is a powerful oxidizing agent. The sodium bicarbonate/ citric acid reaction produces less CO_2 but both chemicals are relatively innocuous.

Experiments were conducted to evaluate these two reactions with respect to the following criteria: (1) the reaction starting speed; (2) the CO_2 yield; and (3) the temperature change involved in the reaction.

(2) <u>Reaction Starting Speed</u>

Both reactions are initiated by the presence of water. When oxalic acid, potassium permanganate, and water were mixed, reaction took place within 0 to 5 seconds. Instantaneous reaction occured when sodium bicarbonate, citric acid, and water were mixed.

(3) Carbon Dioxide Yield

The CO_2 yield from these two reactions would be effected by many factors. During this preliminary study, only the following variables were evaluated: (1) the weight proportions of the chemicals and water; and (2) the order of mixing of the reactants.

Best results obtained from the preliminary study on the variables were obtained in the following two experiments:

- Potassium permanganate (35 g) was dissolved in 20 g of water. When oxalic acid (70 g) was added to the $KMnO_4$ solution, reaction took place within 5 seconds, and a total of 68.5 g of CO_2 and water vapor was produced. This amount of gas would occupy 1.23 cu ft at standard conditions. For this particular reaction, the actually required amount (35 g) of $KMnO_4$ was far less than the theoretical figure (82 g). The amount of gas produced was very close to theoretical yield. However, together with the CO_2 generated, a certain amount of water vapor was produced by vaporization by the heat of reaction.

- Citric acid (25 g) was dissolved in 20 g of water. Because of the negative heat of solution, the water was cooled by this process to below room temperature (25°C). When the solution temperature was restored to 25°C, 20 g of sodium bicarbonate were added. Reaction started immediately and 10 g of CO_2 was produced. For this reaction, the amount of citric acid (25 g) used was more than the theoretical value (about 15 g). The CO_2 yield based on $NaHCO_3$ was close to the theoretical amount. Although this reaction could be initiated instantly, it was not completed as rapidly as the oxalic acid/ $KMnO_4$ reaction.

(4) Temperature Change

When 70 g of oxalic acid was oxidized with 35 g of $KMnO_4$ (in 20 g of water), the temperature of the reaction mixture rose from 25°C to 70°C. Thus, the employment of water served two purposes: (1) to start the reaction, and (2) to absorb the heat of the reaction. However, when excess water was added, the CO_2 yield was reduced.

When 20 g of $NaHCO_3$ was reacted with 25 g of citric acid (in 20 g of water) the temperature of the reaction mixture fell from 25°C down to 8°C. In this case, the water supplied the heat of reaction and started the reaction at the same time. Again, the CO_2 yield would be less when more water was used.

This gas generation system could fit into the foam flotation system as follows: The chemically produced gas may be used for the inflation of the chemical gas generating unit; thus, only a lightweight container is required.

(5) Areas of Future Work

Future work on the gas-producing unit should include the following:

- Determine the amount of gas required for the proper inflation of the collapsed foam necessary to float the armor.
- Determine the amount of chemicals for the generation of this amount of gas.
- Design the gas-generating unit.
- Check the possible hazards of oxalic acid and potassium permanganate under normal conditions of use.
- Improve the $NaHCO_3$/citric acid reaction in two respects:
    - Optimize the weight proportion of the reacting chemicals, and
    - Speed up the reaction completion rate.

(6) Summary

CO_2 can be produced instantly at room temperature under atmospheric pressure either by the oxidation of oxalic acid with $KMnO_4$ or from the $NaHCO_3$/citric acid reaction. Both reactions could be started by the presence of water.

An instant gas-producing unit can be designed. For generating the same amount of gas, it will be lighter than the compressed gas cylinder. These reactions may be substitutes for the compressed gas in furnishing gas for the inflation of the collapsed foam systems under water.

J. Overall Rating of Concepts

During the course of the program (at the end of Phases 1 and 2) the approaches were rated.

The six design concepts were rated on a numerical scale as follows:

10 Excellent
7 Very good
5 Average
2 Fair
0 Poor

The rating was done independently by three people who were familiar with the project, and the number value was the average of their ratings. The concepts were judged on the basis of 14 criteria. An overall merit rating was arrived at by summation of the individual scores. The results of the evaluation at the ends of Phase 1 is shown in Table 10. Those at the end of Phase 2 are shown in Table 11. The results of these early evaluations, prior to building the first models, are in good agreement of the final test results.

3. RECOMMENDATIONS

It is recommended that the form, size, and type of construction of a proposed new armor carrier be definitely established. Once this is fixed, the amount of buoyancy inherent in the new carrier plus armor with foam cover over the top edge should be determined. Any flotation already present in the armor system does not have to be provided for by the auxiliary flotation system. By providing as much buoyancy in the armor and carrier as possible, the size of the foam blocks, foam generator systems, or foam component storage tank can be reduced so that they more nearly approach acceptable sizes.

Once the amount of flotation actually needed is determined, the feasibility should be investigated of using precompressed foam or the polyurethane system to provide the additional needed flotation.

The possibility of placing the foam system under the armor has been proposed by personnel at Natick. It is believed that this concept has merit, but should only be pursued if a positive means of jettisoning the armor prior to foam deployment can be developed.

Table 10

EVALUATION OF CONCEPTS

Criteria for Evaluation[1]	Preformed Foam	Instant Polystyrene	Urethane	Bubble-Pack	Open Cell Foam Plus Closed Cell Foam	Hybrid
Compatibility with Armor System	8	6	5	2	2	6
Weight--4 lbs max	8	6	5	9	8	5
Volume--48 (cu in.)	5	6	5	0	1	5
Safety	10	5	5	10	10	5
Storage Stability	6	10	7	10	8	6
Deployment Speed	7	6	7	10	10	6
Accidental Activation	9	10	4	10	10	4
Fail-Safe	5	8	8	3	3	5
Resistance to Projectiles	8	9	8	7	10	8
Position Sensitivity	10	6	7	10	10	7
Complexity of System	9	8	4	10	10	4
Stage of Development	8	7	5	1	1	5
Human Factors	8	6	6	1	1	6
Ease of Manufacture	8	7	6	2	1	6
Merit Number	109	100	82	85[2]	85[2]	78

[1]Items such as intrinsic buoyancy, ease of actuation, sizing and effect on armor were not rated as their effect would be the same in all concepts.

[2]These concepts rate higher than polyurethane foam, but equipment using them would have to be worn in the fully deployed condition. As such, they would be unacceptable.

Table 11

EVALUATION OF DESIGN CONCEPTS

Criteria for Evaluation[1]	Preformed Foam	Instant Polystyrene	Urethane	Hybrid of 1 & 2
Compatibility with Armor System	8	6	5	6
Weight--4 lbs. max	10	8	6	8
Volume--48 (cu in.)	6	6	4	6
Safety	10	5	5	5
Storage Stability	8	10	7	8
Deployment Speed	7	8	7	7
Accidental Activation	9	10	4	9
Fail-Safe	5	8	8	5
Resistance to Projectiles	8	9	6	8
Position Sensitivity	10	9	6	9
Complexity of System	9	7	2	7
Stage of Development	8	7	3	7
Human Factors	8	6	3	6
Ease of Manufacture	8	8	4	6
Merit Number	114	107	70	104

[1]Items such as intrinsic buoyancy, ease of actuation, sizing and effect on armor were not rated as their effect would be in the same in all concepts.

4. SUMMARY

A program to investigate the feasibility of using foams to provide rapid and unsinkable flotation for personnel wearing body armor was undertaken in three phases:

(1) Study of a number of concepts that might be used (Phase 1),

(2) Design of flotation gear for three selected concepts (Phase 2), and

(3) Fabrication of prototype models of the selected concepts and designs (Phase 3).

During Phase 1 of this program three approaches were extensively investigated to provide flotation for a man wearing body armor. They were:

(1) The use of preformed, flexible foam.

(2) The use of polystyrene foam formed from polystyrene dissolved in liquefied gas.

(3) The use of rapid-reacting urethane foams.

Two approaches, (1) the use of commercial "Bubble-pack" materia; and (2) the use of an open-celled foam containing beads of expanded closed-cell foam, were also considered. No work was done on these approaches because they entail wearing the flotation gear in the fully deployed condition, which would be cumbersome and unacceptable to the user.

Hybrid systems of 1, 2 or 3 were considered, but no work was done on them because their development depends on defining the use conditions of the basic systems involved.

Of the three concepts proposed, the use of preformed foam appeared to be the best choice. Polystyrene foam made from liquefied gas solutions is a good material except for the difficulty experienced in making these foams flow around corners. Polyurethane foams were also good, but the equipment needed for their generation was more complex than that needed for other systems.

Automatic means of actuating the flotation devices were investigated and several ways of accomplishing this were conceived and tested.

The generation of gas for inflation from dry chemicals and water was investigated. Two potentially useful chemical systems were found.

In Phase 2, work on the development of rapid reaction flotation systems for men wearing armor detailed plans and specifications were developed for each of three proposed design concepts, i.e.:

(1) Collapsed, preformed flexible foam;

(2) Instantly-generated polystyrene foam; and

(3) Rapidly-generated polyurethane foam.

Each concept was evaluated. It was recommended that the building of systems proceed using concepts 1 and 2. Concept 3 was not recommended because of the complexity and size of the generating equipment.

A hybrid system using concepts 1 and 2 was discussed and recommended as a back-up development for later work as necessary.

The preformed flexible foam as a flotation system was evaluated. The problem of compression set did not appear to be a serious one.

Under certain conditions of damage to the foam package preformed foam lost about one-third of its buoyancy after 6 hours in the water. Means of minimizing the loss of buoyancy were developed. The designs presented in Phase 2 were not accepted and a redesign program thus had to be superimposed on the fabrication phase. (Phase 3).

Life jackets for personnel wearing armor were made and tested during Phase 3 of this program. The jackets were permanently attached to the present armor carrier.

These life jackets used foam as the flotation material. Three concepts of using foam in different forms were utilized:

- Precompressed flexible polyurethane foam that is deployed at the time of use by the introduction of a gas.
- Generation of a polystyrene foam from a solution of the polymer in a liquefied gas at the time of use.
- Generation of a polyurethane foam from its components (a polyol and an isocyanate) at the time of use.

Each of these approaches required a different design for the jacket. These designs were tested both in air and in water on a man wearing them.

The precompressed foam with gas deployment system performed well. This system was fully automatic and functional on contact with water.

The precompressed foam system is the furthest advanced toward being a workable system. It could become a pracical system with little additional work.

The polystyrene foam generated from a polymer solution in liquefied gas suffered from two major difficulties. The polymer solvent (dimethyl ether) is flammable and the foam will not flow around corners, or follow a contour. It is not moldable. No ready solution to these difficulties is apparent at this time.

The polyurethane foam generated from the appropriate reactants could be made into a workable system by a redesign of the liquid reactant container valves and by assembling the reactant tubes in the vest and armor carrier so that they cannot be pinched off.

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13. ABSTRACT

A feasibility study was conducted on approaches to using foams in flotation systems for personnel wearing body armor.

Flotation systems should be rapidly deployable (10 seconds) and provide flotation for at least six hours, even if damaged. These systems should not interfere with the wearer as he performs his duties.

Three approaches were investigated: (1) the use of preformed flexible foam; (2) instantly generated polystyrene foam; and (3) fast reacting two-component urethane foams.

Only the preformed flexible foam performed well when fabricated into a jacket and tested on a man.

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